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Popular Mechanics

TECH AUTO HOME ADVENTURE SCIENCE

THE QUEST FOR 1000 MPH

BUILDING THE WORLD'S FASTEST CAR p. 68

ONE JET ENGINE +
ONE ROCKET ENGINE =
0–1000 IN 55 SECONDS



ISSUE
MARCH
2014
Since 1902

MUSTANG REBORN p. 46

POPMECH'S MOVIE TECH AWARDS p. 54

EASY GADGET FIXES p. 88

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Popular Mechanics AUTOMOTIVE EXCELLENCE AWARDS 2014

[1]AutoPacific segmentation. MY14 Versa Note vs. 2013 Economy Compact class, 5-passenger vehicles, excluding electrics and hybrids. [2]2014 EPA fuel economy estimate, 40 MPG highway for Versa Note with CVT. Actual mileage may vary – use for comparison only. [3]Available feature. Parking aid/convenience feature. Cannot completely eliminate blind spots. May not detect every object and does not warn of moving objects. Always check surroundings before moving vehicle. Not a substitute for proper backing procedures. Always turn to check what is behind you before backing up. Always wear your seat belt, and please don't drink and drive. ©2014 Nissan North America, Inc.

PopMech

MARCH 2014

The Bloodhound SSC's EuroJet EJ200 turbofan engine.



The 1000 MPH Car Does Not Exist—Yet 68
Not content to own the land speed record of 763 mph, a British team shoots for 1000 mph or more. Behold, the making of the world's fastest car. **BY ANDREW ENGLISH**

Getting Started in 3D Printing 76
About 5 minutes ago, or so it seems, 3D printers were novelty machines for making plastic toys. Now that they've sparked a new manufacturing trend, it's time to learn how to use one. **BY LEE H. GOLDBERG**

The Armageddon Club 80
As more nations develop nuclear-strike capability, a ready U.S. arsenal becomes more crucial. PopMech gets a rare ringside seat at an ICBM test launch—and meets the elite cadre of airmen who turn the keys. **BY JOE PAPPALARDO**



ON THE COVER

Illustrator Graham Hutchings worked with the Bloodhound SSC's 3D CAD files to create PopMech's March cover image of the land-speed challenger.

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Second Annual CinemaTech Awards 54
Movies drive tech innovation. PopMech picks the year's best in special effects and other visual artistry. BY ADAM SAVAGE

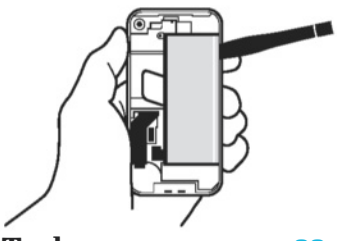
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Vacationing on the high seas is all fun and games, until it's not. Read this before you book a cruise. BY KALEE THOMPSON

The Design-It-Yourself Revolution 62
A custom ax for $850? Impossible—unless you turn to Moniker Guitars, the innovative Austin, Texas, startup. BY CHRIS RAYMOND

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WEEKEND



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One bad tumble can bust up a gadget. But with a little tech know-how, you can do your own repairs and save big.
Digital Clinic Online P2P payment systems are proliferating. Which one is for you?



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Take the guesswork out of your commute with driving apps to plan your route, save money on gas, and avoid dreaded traffic snarls.
Car Clinic Prolonging battery life and other auto fixes.



Home 100
As incandescents disappear, our LED guide helps you pick the best bulbs for your home.
Tool Test Eight right-angle drills, three top picks.
Home Clinic Make your outlets more USB-friendly.

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An epic tale with ancient Greeks, Ben Franklin, and a cartoon bear.

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WHAT YOU SAID

(ABOUT OUR DECEMBER/JANUARY ISSUE AND MORE)

We read all your comments, tweets, and letters. Now we know that you love sci-fi as much as we do.
Edited by Darren Orf

In our December/January issue we let the real experts—actual scientists—pick the Top 10 sci-fi movies, got high on airships, provided a succinct guide to the private space industry, and more. ● In "Mosaic Theory," columnist Glenn Harlan Reynolds explored how license-plate scanners can plot a car's movement. One reader proposed a side step. "There is a simple and widely used means to prevent your license plate from being tracked: the bicycle," Mitchell Small writes. ● Readers agreed with the choices in "The 10 Best Sci-Fi Movies Ever," with a few exceptions. "How can you not give *Forbidden Planet* a mention?" Pat Bowen of Palatka, Fla., writes. Pat has a point: The famous space romp influenced many filmmakers. ● Our story about the Aeroscraft gave reader Paul Pepe of Massapequa, N.Y., a lift. "The possible uses of the Aeroscraft boggle the imagination," he writes. Indeed, the age-old dream of airships holds new power to inspire.



WHAT WE'RE UP TO

(POPMECH NEWS & EVENTS & STAFFERS ON THE SCENE)

Online editor Andrew Moseman traveled to Miami to try out Qualcomm's next-gen stadium tech—and to watch the Patriots' QB Tom Brady throw a game-losing pick. Also in Florida, *senior news editor Joe Pappalardo* witnessed advanced bots in DARPA's Robotics Challenge, as they drove cars, climbed ladders, and more. *Associate tech editor Davey Alba* and other members of the PopMech team traveled to Las Vegas for the 2014 CES. We saw scads of cutting-edge technology, including 3D-printing gear, automotive tech, and lots of new phones and tablets. We're still recovering.



COMPLAINTS DEPARTMENT

Time for Popular Mechanics to get back to the basics. That is why I subscribed in the first place.
BILL ROVAN, LINCOLNTON, GA.

WE'RE REALLY BUSY IN MARCH

MARCH 17: Game Developers Conference, San Francisco • TEDActive 2014, Whistler, British Columbia • **MARCH 29:** The 26th Annual IEEE Software Technology Conference, Long Beach, Calif.

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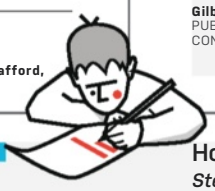
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THE KID WANTS TO KNOW

Are you a kid with a question? Ask Darren!

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How close are scientists to creating artificial intelligence?

Steven E., 10, Weston, Mass.

Artificial intelligence exists insofar as computers can recognize and respond to patterns. But Google research director Peter Norvig says computers lack insight to "handle the broad range of tasks that people can." — *DARREN ORF*

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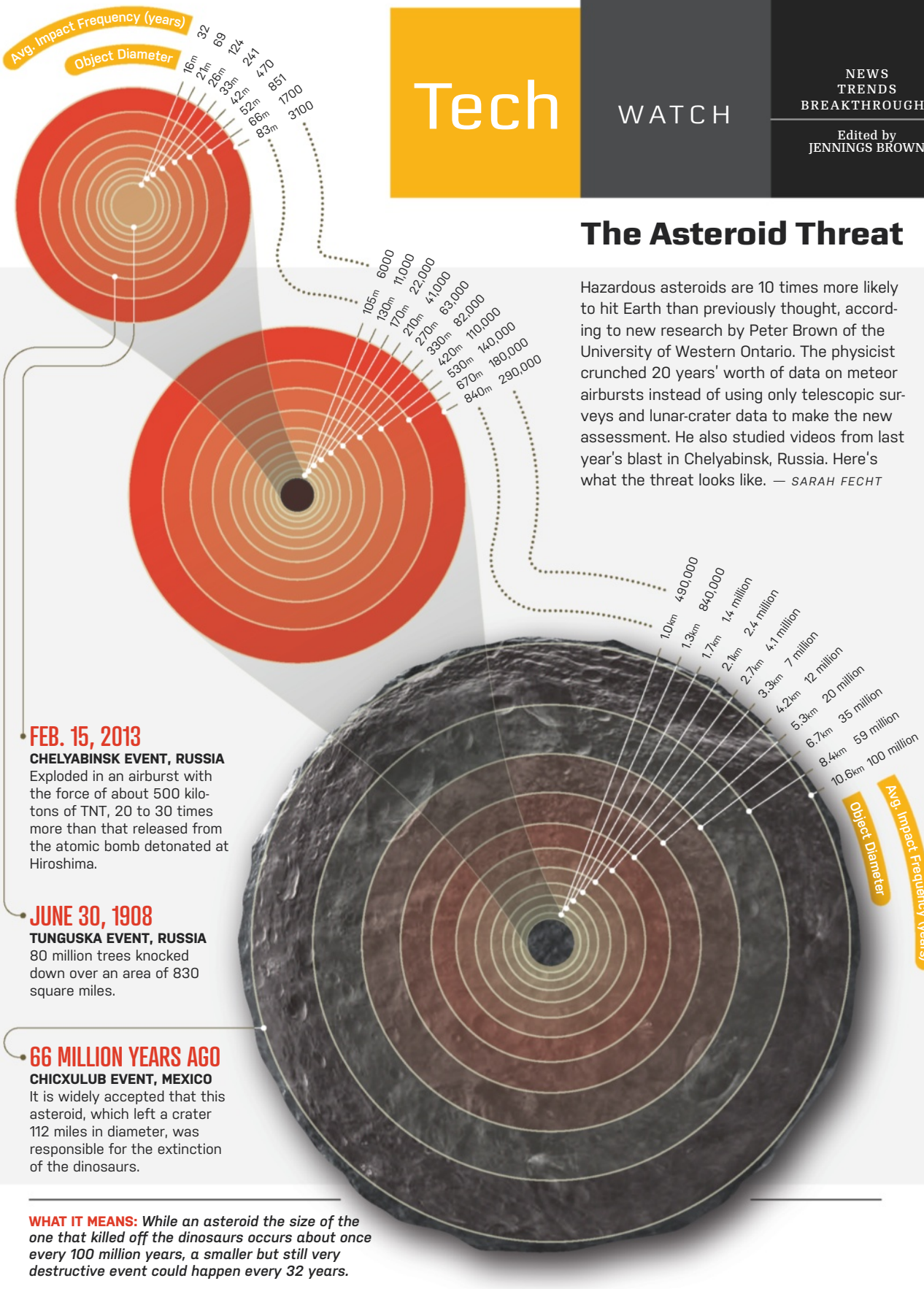
Tech WATCH

NEWS
TRENDS
BREAKTHROUGHS

Edited by
JENNINGS BROWN

The Asteroid Threat

Hazardous asteroids are 10 times more likely to hit Earth than previously thought, according to new research by Peter Brown of the University of Western Ontario. The physicist crunched 20 years' worth of data on meteor airbursts instead of using only telescopic surveys and lunar-crater data to make the new assessment. He also studied videos from last year's blast in Chelyabinsk, Russia. Here's what the threat looks like. — *SARAH FECHT*



FEB. 15, 2013

CHELYABINSK EVENT, RUSSIA
Exploded in an airburst with the force of about 500 kilotons of TNT, 20 to 30 times more than that released from the atomic bomb detonated at Hiroshima.

JUNE 30, 1908

TUNGUSKA EVENT, RUSSIA
80 million trees knocked down over an area of 830 square miles.

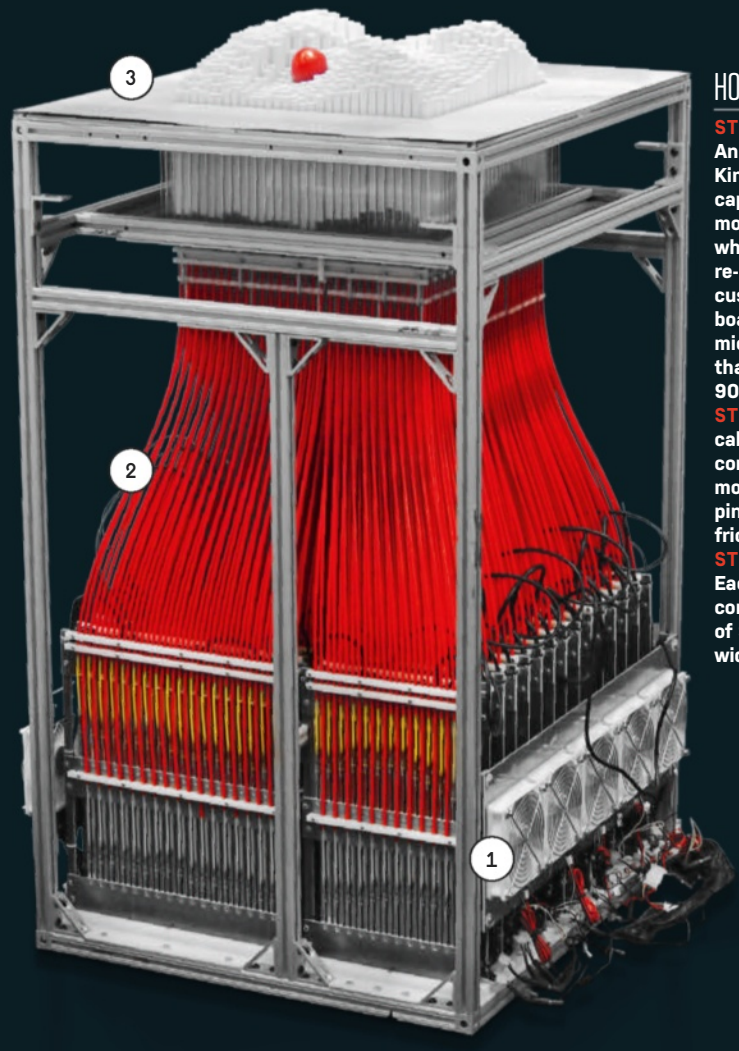
66 MILLION YEARS AGO

CHICXULUB EVENT, MEXICO
It is widely accepted that this asteroid, which left a crater 112 miles in diameter, was responsible for the extinction of the dinosaurs.

WHAT IT MEANS: *While an asteroid the size of the one that killed off the dinosaurs occurs about once every 100 million years, a smaller but still very destructive event could happen every 32 years.*

Rise From the Surface

Prototypes form in an instant, far more quickly than in 3D printing. Medical CT scans, 3D maps, and architectural designs morph as new data is input. This is the "radical atoms" vision of Massachusetts Institute of Technology's Tangible Media Group, which believes that, in many cases, physical is better than digital. In November 2013 graduate students Daniel Leithinger and Sean Follmer presented the first step of this vision. The inFORM is a shape-shifting surface that captures movement and forms with an overhead sensor, then renders those forms in motion remotely and simultaneously through a motorized, Pinscreen-like device. As the ½-inch-wide pins—there are 900 of them—move up and down in unison, they can create an interactive 3D model of objects anywhere around the world. — *DARREN ORF*

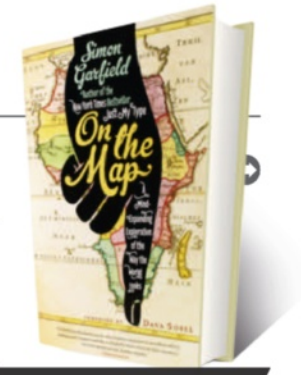


HOW IT WORKS

STEP 1: **An Xbox Kinect sensor captures movement, which is then re-created via a custom circuit board with a microcontroller that operates 900 motors.**

STEP 2: **Long cable linkages connect the motors to pins, reducing friction.**

STEP 3: **Each linkage connects to one of 900 ½-inch-wide pins.**



60-SECOND GENIUS

SIMON GARFIELD, JOURNALIST AND AUTHOR

Q: How have digital maps changed the way we see our place in the world?

A: Today we are always a little blue dot in the middle of every map. But often that map is only 2 inches by 3 inches on your phone screen, which means that we get a very limited view of what's around us. We look at the world in a very egocentric way when we can travel across the country without really knowing how we got there because we're just following GPS. We lose a grander scale of our place in the world and how significant we are. When we look at the maps on our phones, we think, oh, this is amazing. I'm at the center of the world! But, of course, we are not at all.

— *AS TOLD TO ALYSON SHEPPARD*

PHOTOGRAPH BY DFKI/DANIEL KÜHN (INFORM), PHILIP FRIEDMAN (BOOK)



The Marines Meet Their Robot Mule

There's a robot following Marine Pfc. Marcus Beedle through the woods at Fort Devens, Mass. The quadruped, the Legged Squad Support System (LS3), does this by using flickering lasers and stereoscopic cameras in its head to fixate on a pattern of thick bands strapped to the Marine's backpack. The robot also traces the path Beedle takes by tracking a navigation device strapped to his right boot. LS3 can pick its own way through rough terrain or tramp directly in its master's footsteps. "Follow-the-leader is our bread and butter," says Kevin Blankespoor, VP of controls and autonomy at Boston Dynamics (purchased by Google in December 2013), the creator of LS3. Beedle and a squad of Marines from the 1st Battalion, 5th Regiment, are the first to take this robotic pack mule for squad-level testing. PM is the only media outlet on hand for this historic meet-up of Marine and machine. Officials from the Marine Corps Warfighting Lab, DARPA, and Boston Dynamics developed the LS3 to go where tracked and wheeled vehicles can't go—over rocks, up and down steep inclines, and through woods and swamps. The idea behind the LS3 is for Marines to use it to take supplies to their secured positions. LS3 is made for war zones, but it is not viewed as a weapon. It's just a mule—though some Marines would like to see that change. "We'd love a machine gun on it," says 1st Lt. Alex Hurran. — *JOE PAPPALARDO*

OTHER BIOMIMIC BOTS



LEMUR JPL unveiled the latest generation of what it's calling the world's first climbing robot. The JPL/NASA LEMUR IIB uses 750 tiny claws on each of its four arms to firmly latch on to a rock surface. The primate-like machine could provide the anchor for asteroid-mining bots or drills operated by astronauts.
— *MICHAEL BELFIORE*



CHEETAH A cheetah copes with its high center of gravity by whipping its tail to counteract the torque of sudden turns. Dima, a big-wheeled robot built at the University of Cape Town, uses the same approach with a tail that swings overhead and away from sharp turns. The result: Its rollover-free turn speed more than doubles, from 7 mph in a tailless version to 17 mph.
— *ALEX HUTCHINSON*

PHOTOGRAPH BY **HARRY GOULD HARVEY IV (LS3)**



Quiet as a Feather

STUDYING OWL WINGS COULD INSPIRE NEW NOISE-CANCELING TECH.

Mechanical engineer Justin Jaworski was inspired—and scared—when a great gray owl suddenly flew at his face during a visit to a bird sanctuary. The experience made him wonder how the animal could approach so silently. Using mathematical modeling and wind-tunnel experiments, he showed that the owl's wing is designed for stealth attack. Jaworski says that elements of the wing could be replicated to mitigate noise. Here are three fields that could benefit from silent owl technology. — *S.F.*

WIND TURBINES

Owl wings cut down on the noise of air moving over them, called turbulence. The leading edges of an owl's primary feathers are serrated, which breaks up air turbulence into smaller currents that cause less noise. A similar comblike design could help eliminate the whooshing sounds of wind turbines.

AIRPLANES

Owls have flexible and porous feathers along the trailing edge of the wing that appear to mute the sound of airflow off the back of the wing, the same place where much of an aircraft's noise is generated. Models have suggested that a flexible and porous trailing edge made of Mylar could reduce the roar off an aircraft's wing tenfold.

SUBMARINES

The barbed fibers of an owl's down interlock with other feathers, creating a dampening buffer between the rough surface and the air flowing over it. Jaworski is working with the Office of Naval Research to apply similarly smooth, porous surfaces to submarine hulls to try to cut down noise without creating drag.

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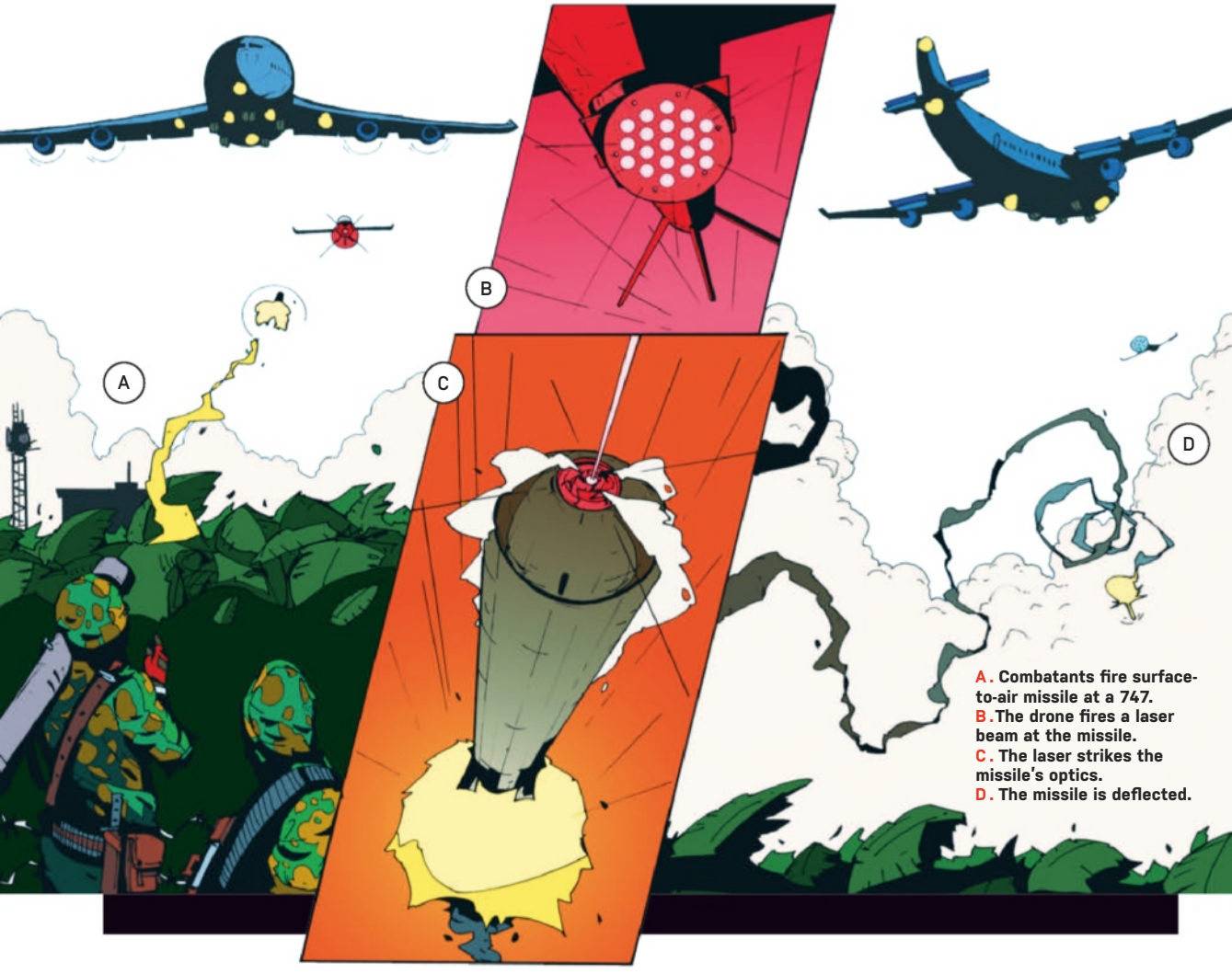


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A. Combatants fire surface-to-air missile at a 747.
B. The drone fires a laser beam at the missile.
C. The laser strikes the missile's optics.
D. The missile is deflected.

Laser-Drone Wars

Four years ago the Airborne Laser Test Bed, a modified 747 that shoots lethal photons, destroyed a ballistic missile in flight by blasting it with a chemical laser. But after its test demonstration, the Pentagon mothballed the plane because of its $100-million-a-year price tag. Still, the dream of flying laser weapons won't rest in the boneyard if DARPA has anything to do with it. The agency is researching fiber-optic lasers as an alternative to massive chemical lasers. Lockheed Martin and Northrop Grumman were awarded contracts to build a prototype for a classified program called Endurance. Instead of blowing up a missile, this system will target optically guided missiles. The program can take advantage of lightweight lasers on drones because it takes less power to scorch optics than to melt a rocket casing. This technology could protect combat aircraft or counter terrorist threats to commercial airlines. — *OLIVIA KOSKI*

WHY FIBER?

HIGHER QUALITY Fiber lasers have near-perfect beam quality, which is a measure of how much energy can be focused in one area. Endurance will combine dozens of fiber-laser beams into one with superb beam quality.

MATURE The telecom boom of the '90s accelerated fiber-optic tech. When the industry went bust in 2001, fiber companies found a new market: high-power fiber lasers for manufacturing. That means they're designed to be reliable.

EFFICIENT The material of most high-power fiber lasers has a high quantum efficiency; the wavelength of light energizing the laser is close to that of the laser's output color. Fewer photons are wasted, and the system weighs less.

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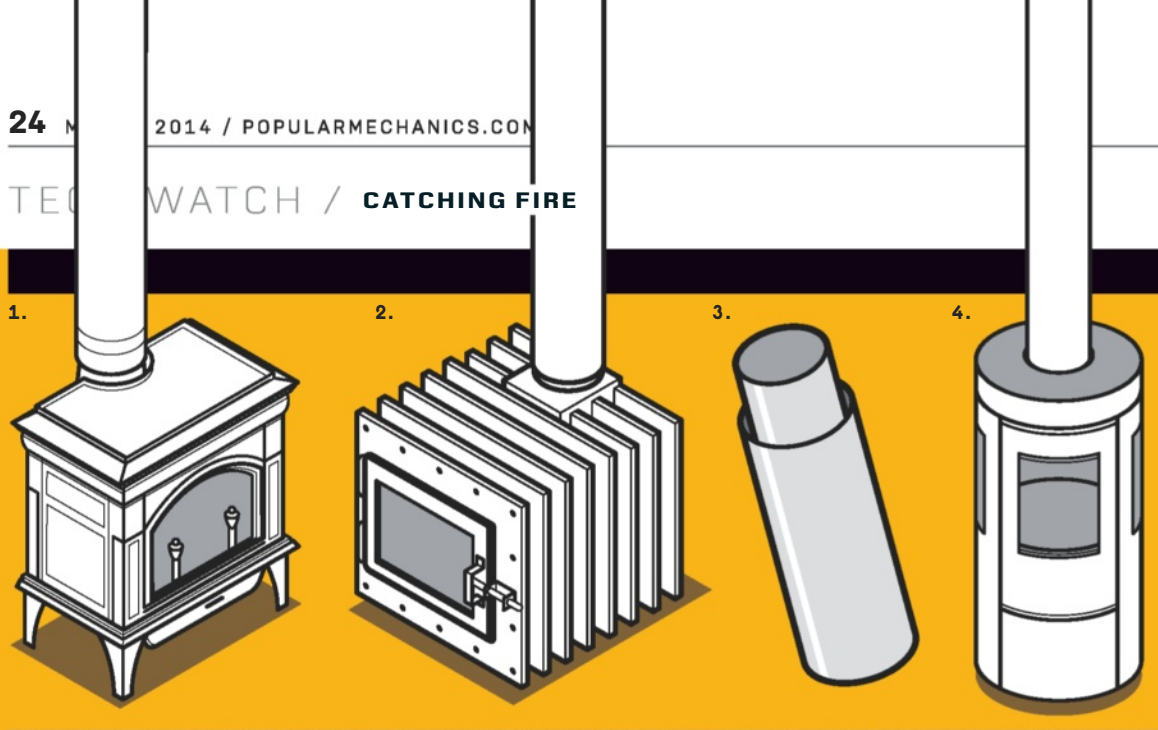
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Woodstove Renaissance

For the roughly 10 million American households that rely on burning wood as a primary heat source, the Alliance for Green Heat's Wood Stove Decathlon could provide a breath of fresh air. The PM-sponsored event challenged 12 finalists to design and build innovative woodstoves that are cleaner-burning, more efficient, easier to operate, and more affordable than the smoke-belching boxes of old. Woodstock Soapstone's Ideal Steel Hybrid took the $25,000 grand prize after six days of testing on the National Mall in Washington, D.C. However, there was plenty of innovation to go around, proving that man's oldest technology can still be cutting-edge. — *DAVID AGRELL*

TWICE BURNED

Smoke from a chimney is simply unburned fuel. Efficient stoves are inherently cleaner because they consume more matter before it leaves the firebox. Both the winning stove, Woodstock Soapstone's Ideal Steel Hybrid, and runner-up Lopi Cape Cod **[1]** draw exhaust gases into a secondary chamber where temperatures can reach 1800 F—hot enough to incinerate all particulates. The Wittus Twinfire, also a runner-up, achieves a similar effect by drawing hot gases from the fire into a lower chamber.

NEW CONCEPTS

Before the decathlon, Team Mulciber—a group of fire-protection-engineering students at the University of Maryland—had never built a stove. Unencumbered by centuries of design habits, they created an innovative stove **[2]** that features a pressurized combustion chamber, an automation system, a custom catalyst and a self-cleaning particulate filter, and a coaxial chimney stack that forces hot air back into the firebox, where it continues the combustion process. The stove's emissions were so low, they were almost unmeasurable.

SMART RETROFIT

Outdated stoves can be retrofit to be more efficient. Those with advanced mechanical skills can install SmartStove, which adds computer-controlled automation to almost any noncatalytic stove that has manual draft controls. A more low-tech solution is the IntensiFire firebox insert **[3]**, an affordable spherical device that recaptures heat before it disappears up the chimney stack.

SET AND FORGET

Incorrectly operated stoves waste fuel, damage stacks, and pollute neighborhoods. One-third of the Wood Stove Decathlon finalists used automation systems to help improve combustion within the stove. HWAM's Autopilot stove **[4]**, which ranked first in innovation, incorporates a thermocouple and an oxygen sensor to analyze the fire's performance and then automatically adjust air vents for a more complete burn.

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ILLUSTRATIONS BY **MARTIN LAKSMAN**

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Josef Newgarden, Champion IZOD Indy Car Series Driver
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RZT S Zero-Turn Rider
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The Cub Cadet RZT® S went toe-to-toe with Josef Newgarden's other high-performance ride at the Indianapolis Motor Speedway. And while the car averaged more than 220 mph, the RZT S zero-turn rider ran circles around it. Pulling zero-turns in just over two seconds, cornering obstacles nimbly and delivering a beautiful cut every time. And off the track, it takes on straightaways and steep banks like nothing else on earth; making a spin on the RZT S almost as much fun as a lap at Indy. Looks like Josef's next pit stop just may be his local Cub Cadet dealer.



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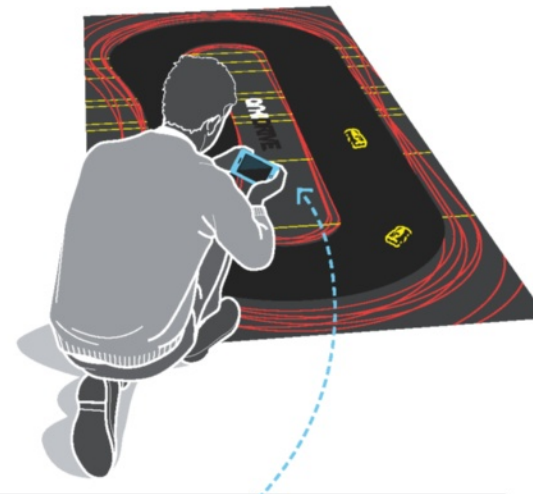


Robo Rods

THE ANKI DRIVE LEARNS TO THINK ON ITS OWN AS YOU PLAY. BEWARE YOUR TOY OVERLORDS.

UPGRADE

Gaming drives off the screen and into the physical world with Anki Drive ($200), which pits iPhone-controlled, artificial intelligence–enabled robotic cars against one another in a weaponized demolition derby. Designed by grads of the Robotics Institute at Carnegie Mellon University, the game plays out on a portable mat encoded with digital markers. As the Hot Wheels–size racers zip around a track, the markers map the vehicles' patterns, allowing the other cars to learn the most advantageous places and moments for firing shots at opponents. A competitor senses a hit when his ***phone/controller*** vibrates. As players rack up points, they earn upgrades they can use to customize their cars—for instance, more armor and greater destructive powers. This game won over the PopMech staff but made us miss a few deadlines in the process. Sorry, boss. — *DARREN ORF*



BEST VS BUDGET

Field Watches

The classic field watch has recently seen a surge in popularity. No matter what the price tag, it's easy to find a timepiece as rugged and reliable as a set of fatigues. — *ALYSON SHEPPARD*

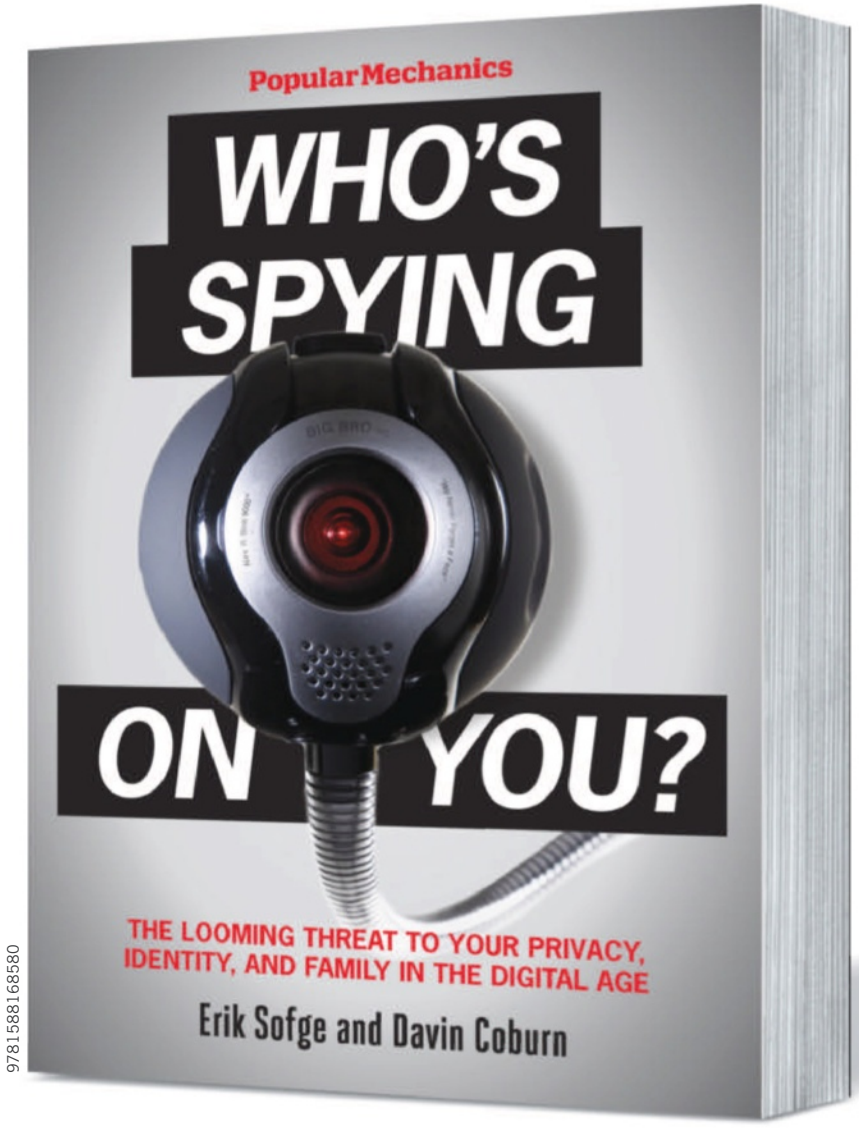


HAMILTON KHAKI FIELD MECHANICAL, $395
Convince your coworkers you're the safari type with this handsome Hamilton, which has a super-hard sapphire-crystal face that keeps its guts dry up to 164 feet underwater. The tough band will keep the ticker secure during bumpy Subaru rides. In fact, it'll last until the next time field watches are in vogue.

TIMEX FOR J.CREW VINTAGE FIELD ARMY WATCH, $98
This retro-inspired, faux-distressed example has a softer, mineral-glass-crystal face, but a few scratches only improve the look. Though it's not as sturdy as the Hamilton, the Timex is easier on your wallet, so you'll feel more comfortable treating it with the appropriate roughness a field watch deserves.

ILLUSTRATION BY **MARTIN LAKSMAN**

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Today, our every activity can be quietly monitored, from who our friends are to all of our financial transactions. And with medical records in the "cloud" and imminent gene sequencing, even our bodies are up for grabs. What can we do? From phone hacking to identity and credit theft, *Who's Spying On You?* tells the stories of real people whose privacy has been violated, describes the technologies used to intrude, and reveals how we can protect ourselves in a world filled with spies.

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UPGRADE / **EDITORS' PICKS**



WICKED S3 SPYDER ARCTIC LASER, $300
We didn't hop on a rocket to verify Wicked's claim that you can see Arctic Laser's beam from space. However, we did use it to burn holes in a dollar bill and a polyester glove with alarming ease. This 2000-milliwatt four-mode laser is not a toy and has to be used with care. But we want one. — *JAIME NETZER*



HARMAN KARDON NOVA, $300
Plastic demiglobes house 2.5-inch drivers, 1.5-inch tweeters, and a bass-producing flute. In our test the Nova's big sound pleased the crew in a crowded living room. — *JOE BARGMANN*



FITBIT FORCE AND FITBIT ARIA, $130 EACH
These two items combine to create the world's most brutally honest and aggressive digital personal trainer. The Force smartwatch and Aria smartscale record nearly every detail of your waking and sleeping life. Like other fitness trackers, the Force uses an accelerometer and altimeter to calculate your activity level and how many calories you burn throughout the day; it even tracks your sleep patterns. The scale measures weight, body-fat percentage, and body-mass index, and, like the watch, syncs wirelessly with your computer and smartphone to chart your progress. The Fitbit online tools can also measure every calorie you consume. Who knew robots could be so darn nosy? — *A.S.*

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Hack Your Ride

Bicycle mechanics—muscles, joints, gears, and chains working in concert—get you from point A to point B. But new technology elevates the bike above this basic task, adding safety, security, style, and even on-the-fly entertainment. — *D.O.*

HAMMERHEAD BIKE NAVIGATION, $85

1 This Kickstarter project takes some of the risk out of GPS-guided rides, helping cyclists keep eyes on the road. Using your phone's GPS, the device flashes easy-to-see colored lights for turns, hazards, and even distances.

BIKESPIKE, $130

2 The next best thing to stopping a bike thief is nailing one after the fact. The BikeSpike app lets users define zones and, if the bicycle leaves them, receive an alert. The bolt-on sensor contains a tracking chip and accelerometer; the latter can trigger a message to the owner or others when a bike crashes or is tampered with.

FOLDYLOCK, $95

3 This Kickstarter-funded Fort Knox of locks is fabricated from hardened steel links and coated in plastic to prevent rust and protect a bike's finish. The segments can withstand a hacksaw and bolt cutter and fold up like a wood ruler to fit into a frame-mounted case.

SCOSCHE BOOMBOTTLE, $140

4 Hydrate via a hands-free system and put your water-bottle holder to better use. This Bluetooth-enabled speaker fits in a bottle cage and pumps out music in all directions.



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UPGRADE / **EDITORS' PICKS**



LITTLEBITS, $100–$200
LittleBits is an Erector set for the digtal age. Unique circuits connect via magnetic modules to become DIY alarm clocks, synth spin tables, and even keytars. All projects are open-source, and the Base Kit includes plenty of modules to get you started—no knowledge of programming, soldering, or wiring required. — *A.S.*



IROBOT BRAAVA, $150
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POPMECH BREW

This recipe was inspired by a pre-Prohibition American lager that we'd like to think readers enjoyed while paging through our earliest issues.

INGREDIENTS

17 pounds American six-row malt
5 pounds flaked corn
1 ounce Cluster hops (bittering)
1 ounce Mt. Hood hops (flavoring)
½ ounce Czech Saaz hops (finishing)
Bavarian lager yeast

MASH SCHEDULE

1. 95 F for 15 minutes.
2. 122 F for 30 minutes.
3. 138 F for 15 minutes.
4. 154 F for 45 minutes.
5. Mash out for 15 minutes at 164 F.

H

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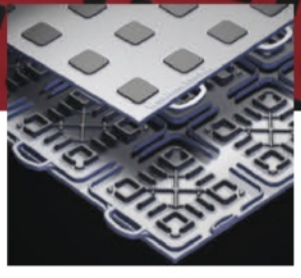
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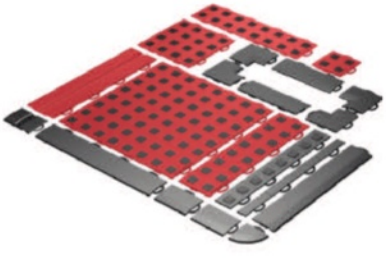
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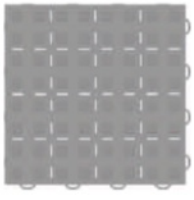
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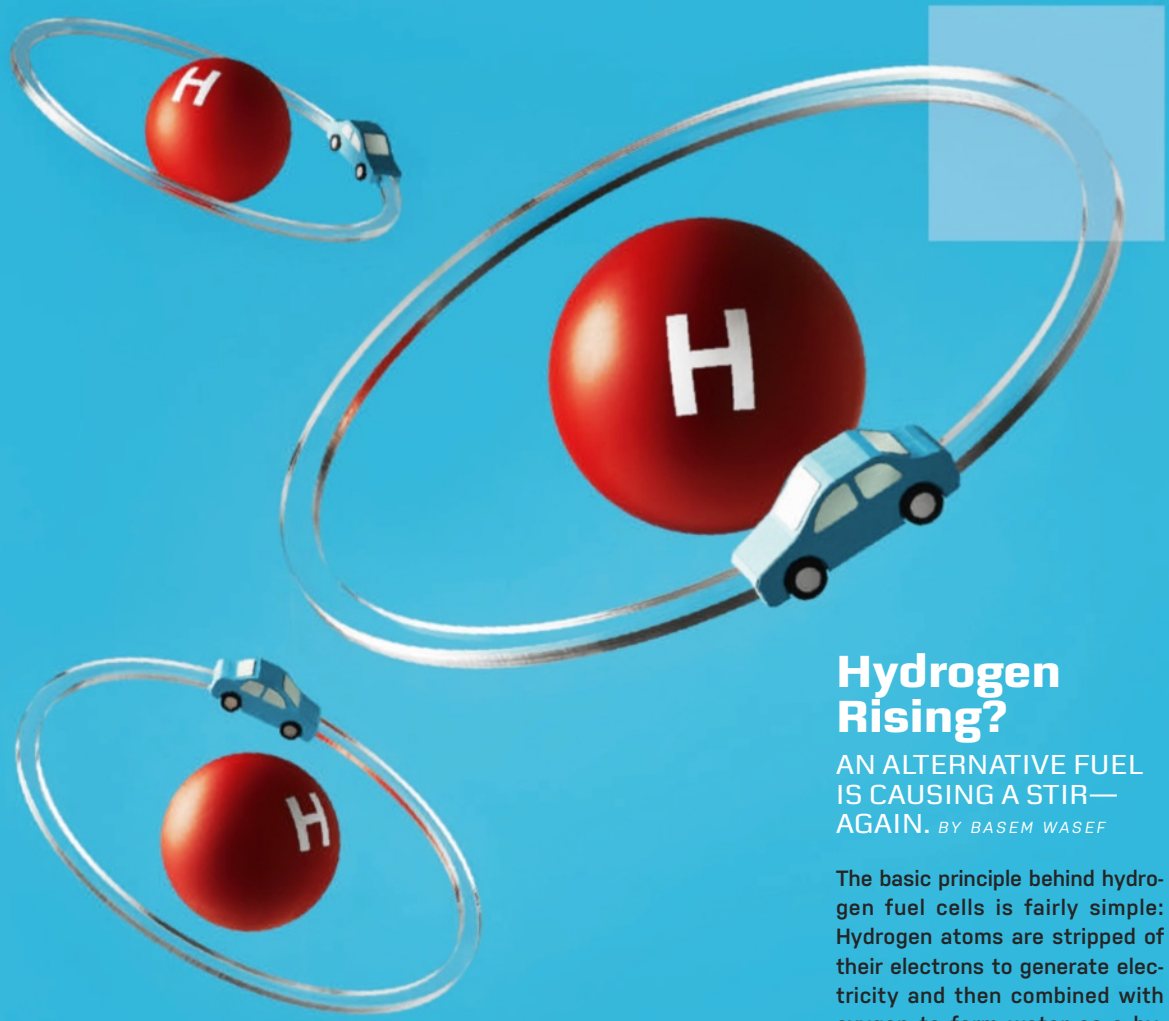
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Hydrogen Rising?

AN ALTERNATIVE FUEL IS CAUSING A STIR—AGAIN. *BY BASEM WASEF*

The basic principle behind hydrogen fuel cells is fairly simple: Hydrogen atoms are stripped of their electrons to generate electricity and then combined with oxygen to form water as a by-product. Mainstream deployment of fuel-cell vehicles, though, has proved to be complex. Compared with liquid fuels, hydrogen is tough to transport and store. And without a meaningful number of vehicles on the road, there's been no incentive to build hydrogen fuel infrastructure. Now new initiatives in California and across the U.S. are pushing for a long-awaited expansion of the refueling network.

NEW HYDROGEN-FUEL-CELL OPTIONS ARE COMING.

Hyundai's Tucson Fuel Cell is landing in California showrooms now. Production versions of the Toyota FCV and the Honda FCEV concepts unveiled last year should be available sometime in 2015. And automakers are already planning yet another wave of hydrogen vehicles around 2020.



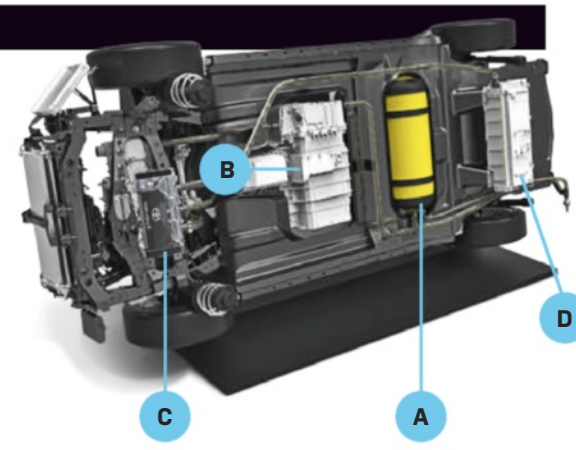
Hyundai Tucson Fuel Cell



Toyota FCV Concept



Honda FCEV Concept



WHERE DOES THE POWER COME FROM? Here's the abridged version: Compressed hydrogen from the storage tank (A) is stripped of its electrons in the fuel-cell stack (B), creating electricity. A power-control unit (C) orchestrates the flow of energy from the stack to the battery (D), which powers the electric motor that moves the car. The battery ensures full power during acceleration until the fuel cell reaches peak voltage. Got all that?

And with the debut of three promising hydrogen-fuel-cell vehicles from Honda, Hyundai, and Toyota, consumers will have new options beginning in 2014. Are we finally seeing the dawn of the hydrogen age? Not so fast.

Why now?

The current hydrogen push has less to do with consumer demand than with government incentives that treat fuel-cell vehicles (FCV) as equal to or better than electric vehicles. In California the combination of 300-mile range and fast refueling gives fuel cells the maximum available zero-emission vehicle (ZEV) credits. That makes it easy for a manufacturer to meet the state's ZEV mandate with fewer cars. On the federal level, both FCVs and EVs get an EPA credit multiplier of 2.0 beginning in 2017, which means that sales of either type of car confer a disproportionate benefit on the ledger for an automaker's entire fleet. In response, manufacturers have formed several high-profile partnerships, including Ford/Daimler/Renault-Nissan, BMW/Toyota, and GM/Honda to develop the vehicles. On the fueling side, a recent infusion of $20 million of funding per year has expanded the California Fuel Cell Partnership's plan to 100 statewide refueling stations. The Department of Energy's H2USA organization wants to use California's efforts as a blueprint for the rest of the nation.

Can I buy a fuel-cell car?

In the past, fuel-cell vehicles have only been available in the hundreds. The three new FCVs slated for production this year and next will increase the volume to thousands, but they will be available primarily in California, where most of the country's hydrogen stations exist. According to Alan Baum, an automotive analyst at Baum and Associates, even if the stations proliferate, fuel-cell vehicles, like EVs, won't dominate the market. "It's not going to be a widespread technology, and for that matter it doesn't need to be," he says. "We're doing an all-hands-on-deck strategy."

Are they practical?

Not according to Tesla and SpaceX founder Elon Musk, who says fuel cells are more of a marketing ploy than a realistic solution. Nissan CEO Carlos Ghosn agrees: "Knowing all the problems we have with charging [EVs], where is the hydrogen infrastructure?" Both men have a bias toward electric vehicles, but the infrastructure issue is a big one. With the current cost of a hydrogen filling station at more than $1 million, neither the government nor the corporate world has any plans for a rapid expansion of the filling network. "We've got electricity everywhere," Baum says. "Putting in 240-volt charging units requires some effort and expense, but it's not game changing. Putting in hydrogen is."

Are they safe?

Yes. Stringent requirements established by the Department of Transportation (DOT) and Society of Automotive Engineers (SAE) ensure that the technology is safe. Automakers are required to build robust hydrogen storage tanks that not only hold the fuel at up to 10,000 psi but also withstand arcane-sounding trials such as "bonfire" and "gunshot" tests by the DOT. Tanks are usually made of several layers of carbon fiber wrapped around aluminum or polyethylene liners, and many are also protected by external layers of steel. Regulations covering PRDs (pressure-relief devices) govern both temperatures and pressures at which gas is released, typically well below what is standard for safe operating conditions.

How green are fuel cells?

It depends on where you look. The only tailpipe emission from an FCV is water, but the process of creating hydrogen fuel—just like that of formulating gasoline or generating current for an electric vehicle—has an environmental

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Rare African Emerald Find Shocks Colombian Cartel

U.S. jeweler seizes more than 10,000 carats and makes history by releasing the One-Carat Pride of Zambia Emerald Ring for UNDER $100!

LUSAKA, ZAMBIA - A recent find of high quality emeralds in this African republic has thrown the luxury gem world into tumult. For hundreds of years, Colombians have controlled the high-end emerald market and sent prices soaring to over $15,000 per carat for top graded stones. But the history-making discovery of Zambian emeralds has revealed a green gemstone with mesmerizing clarity that simply changes everything.

This important find led Stauer, a major gem dealer and importer, to bid on over 10,000 carats. Stauer designed a classic 1-ctw ring for people who love the gem but don't love outrageously priced luxury. Because of their timely buy, Stauer is releasing this exclusive, natural emerald ring—aka ***"The Pride of Zambia"***—to the public for under $100!



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Unfortunately, the window on this exciting emerald opportunity is closing fast. Not long after Stauer acquired their cache, a recent auction saw Zambian emerald prices hit a new record high. The time to act on this great gem value is now, before it's too late. Please call our U.S.-based client service team at 1-888-277-8375 or visit us online at www.stauer.com.

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impact. More than 90 percent of hydrogen today is created using a natural-gas-reforming process involving steam and methane, which reduces CO_2 emissions from "well to wheel" by approximately 60 percent, compared with the process of creating gasoline. So, carbon dioxide is still released into the atmosphere—it just happens before the liquid hydrogen gets to your tank. Incentives and mandates encourage a cleaner hydrogen-creation process: The state of California requires that 30 percent of H_2 supplied for transportation come from renewable sources, which can include wind, solar, and biomass material.

What about refueling?

One advantage of FCVs is that they can travel farther and restore range faster than most current EVs. Refueling is simple: Once a nozzle with a snap collar is securely mated and locked to your car, the transfer of hydrogen begins with a brief hissing sound, followed by a 3- to 5-minute fill-up. However, it takes considerably longer for a filling station to restore the pressure required to service the next vehicle, so current setups can only refuel six or so cars per hour.

So, is hydrogen happening?

"When you have several major carmakers saying we're going to invest in this, that's significant," Baum says. But vehicles are just one piece of the puzzle. Every other player in the hydrogen supply chain, such as the service station industry, needs to invest heavily. Until then, refueling options and vehicle choices will remain extremely limited, with no guarantee of expansion. Which is to say that hydrogen-fuel-cell cars will be a minor footnote in terms of overall vehicle sales for the foreseeable future. For all but the earliest of adopters, hydrogen as a prominent fuel alternative remains somewhere on the horizon.



5 Must-Know Facts About the 2015 Mustang

AMERICA'S ORIGINAL, AFFORDABLE SPEED MACHINE IS ALL-NEW FOR ITS 50TH ANNIVERSARY. *BY BEN STEWART*

1 INDEPENDENT REAR

The Mustang has long been the only passenger car with a solid rear axle. Yes, the 1999–2004 Mustang Cobras offered an independent rear suspension (IRS), but the 2015 is the first model line to entirely ditch the cast-iron beam for IRS. That should make this Stang handle with more precision and ride more comfortably than any before it.

2 TURBO FOUR

Three engine choices will be available for the 2015 Mustang. We've already seen the 3.7-liter V-6 at the bottom of the range, and the lusty 5.0-liter V-8 at the top. But it's the new 2.3-liter EcoBoost four-cylinder, occupying the middle power rung, that has serious potential for fuel economy and fun. Not since the bi-spoilered SVO left the Mustang lineup in 1986 has the pony car used four-cylinder turbo power. This new engine is estimated to deliver 305 hp and 300 lb-ft of torque. More important, the all-aluminum powerhouse should be the lightest of the three engines, reducing the Mustang's



nose weight and increasing agility.

3 DRIVE MODES Another sign of the new Mustang's modernity is optional Driver Select modes that offer on-demand tunability. Flicking individual toggle switches will alter the weighting of the electric power steering, the automatic-transmission shift points, the throttle response, and stability-control intrusiveness. Opt for the GT package and you'll get a standard launch-control system for consistent (and quick) times down the dragstrip.

4 THAT PROFILE Unlike most modern car redesigns, the Mustang doesn't grow in size; it's a fraction of an inch shorter, and the 107.1-inch wheelbase is identical to the last gen's. That's probably because Ford wanted to avoid the cost of an all-new platform. But the updated design adds some gravitas to the Mustang's profile—the track has been widened, the windshield has a faster slope, and the roofline is sleeker.

5 GLOBAL GOALS The Mustang has always symbolized the U.S. overseas. But this is the first of the six generations of Mustangs designed for markets outside the States. Available in the U.S. and Canada in 2014, the sport coupe will head to China, Europe, and even the United Arab Emirates in 2015. The Mustang will even be available as a right-hand-drive model for Great Britain. Blimey, mate!





2014 Cadillac ELR

It will barely make a sound, but the Cadillac ELR will turn heads when it rolls by. Cloaking a mildly revised Chevy Volt plug-in electric powertrain beneath aggressive bodywork inspired by Caddy's Converj Concept, this compact coupe pairs a plush cabin with fetching sheet metal for a posh interpretation of its Chevy cousin. Yet this is more than a reskinned Volt. The ELR also comes with a new front suspension that includes adaptive shocks for eerily flat cornering. The 1.4-liter EV combo puts out a total of 207 hp, 58 more than the Volt, and paddles on the steering wheel provide extra regenerative braking on demand. Too bad flogging this front-drive bad boy through Malibu canyons yielded diminishing returns when it came to seat-of-the-pants gratification. The range in EV mode lands just below the Volt's at 37 miles, but for $76,000 there are sportier and more affordable ways to get your eco-conscious kicks. — *BASEM WASEF*

PRICE: $75,995 AVAILABLE: NOW
MPG (CITY/HWY): 31/35 (GASOLINE MODE), 82 MPGE (COMBINED, EV MODE)



Audi A3 e-tron

BASE PRICE (EST.): $40,000
AVAILABLE: 2015
MPGE (EST.): 157

THE CAR: E-tron is Audi's catchall sub-brand for electric vehicles. And, yes, it's kind of a silly name. The A3 e-tron won't arrive until mid-2015, but we snuck in some wheel time with a prototype.

THE POWERTRAIN: The e-tron uses the same 150-hp 1.4-liter turbocharged four as the Jetta Hybrid, mated to a dual-clutch transmission that has a 101-hp electric motor stuffed in between the flywheel and the gears. The entire system produces 204 hp and 258 lb-ft of torque—enough to hit 60 mph in roughly 7.6 seconds.

THE TORQUE: The electric motors drive the wheels through the transmission, so stepped gear changes happen even in pure EV mode to take advantage of the motor's low-rpm torque. If you stay gentle on acceleration and stick below 80 mph, you can go about 25 miles without using a drop of gas. When the electric range is kaput or the gas pedal is floored, the e-tron switches to hybrid mode. As a hybrid, with full power, it's fun to ride the torque wave through a set of switchbacks.

THE RIDE: Good news here—the e-tron handles like any other Audi. In corners the car feels composed, capable, and sporty. In fact, this is one of the most entertaining plug-in hybrids we've encountered. Can't it just be 2015 already? — *B.S.*

WHEELHOUSE

AUTO ODDS & ENDS

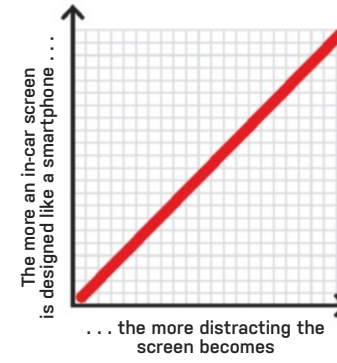
1.2 MILLION

Number of jobs saved by the government bailout of General Motors, according to a recent report by the Center for Automotive Research. All told, the government lost $10 billion on the deal.

MARY BARRA becomes the first female CEO of GM—or any major carmaker, for that matter.

VOLKSWAGENS don't have any USB ports. What's up with that, Vee Dub?

CASUAL OBSERVATION



2014 Subaru XV Crosstrek Hybrid

PRICE: $26,820
AVAILABLE: NOW
MPG (CITY/HWY): 29/33

In the harsh Icelandic winter the 2014 XV Crosstrek Hybrid gave us a preview of Subaru's future. Subie's first-ever hybrid, this version of the 2014 XV Crosstrek has a bit of an experimental feel. But it also shows that Subaru is serious about combining hybrid fuel gains with the AWD capability it's known for. Mating a 13.4-hp electric motor inside its CVT automatic to the 2.0-liter flat-four-cylinder found in the standard XV Crosstrek results in a total of 160 hp and 163 lb-ft of torque—a much-needed improvement over the conventional Crosstrek. The extra 304 pounds of hardware mitigate the extra power, but with 8.7 inches of ground clearance, it's still an impressive all-weather machine. With the XV Hybrid Subaru has something no one else has: a good-looking (if quirky) AWD crossover with creature comforts and tech typical of higher-end vehicles. — *JAMES TATE*



PM FLEET

CARS WE LIVE WITH

2013 HYUNDAI ELANTRA GT

•

PARTING TAKE



"What does the 'GT' stand for?" was the first question we asked when this attractive little compact arrived. While practical, economical, and even sort of fun, the Elantra GT has nothing that shouts out grand touring—much less gran turismo. Which turned out to be just fine with us. We hammered this little car from Detroit to New York to Maine, and everyone who drove it was impressed, especially when we left the highway and hit the curvy two-lane roads where the GT's handling shines. It's light on its feet and entertaining to drive, as long as you don't mind hunting through the gears to find the modest dollop of torque provided by the 1.8-liter engine. (Yes, we opted for the six-speed manual instead of the CVT, because, well, it's a self-respect thing.) And no matter how hard we drove it, we only blew the EPA city rating of 26 mpg twice. We love hatchbacks, and this one feels bigger inside than out, with lots of useful space around the driver and front-seat passenger. In this size and price range, Hyundai has set a nice benchmark. — *JIM MEIGS*

DRIVERS NOTEBOOK

- Love all the handy storage nooks up front.
- Feel every bump on torn-up interstate in New York and Connecticut.

END DATA

BASE PRICE/AS TESTED ▷ **$19,170/$22,015**

MILES DRIVEN ▷ **4955**

MAINTENANCE ▷
Oil change

MAINTENANCE COSTS ▷ **$40**

PM FUEL ECONOMY ▷
Average: 31.6 mpg
Best: 37.3 mpg
Worst: 25.7 mpg



This photo is not real, but it could be in a few years. Nissan says a production version of the BladeGlider is headed for showrooms.

The Future Is Wedge-Shaped

NISSAN'S BLADEGLIDER CONCEPT IS A NEW TAKE ON SPORTS CAR HANDLING.

BY MICHAEL AUSTIN

The wheels on automobiles have been configured in roughly the same rectangular layout for more than a century. Maybe that's why it's so hard to think of the BladeGlider, with its narrow front track and triangular shape, as anything other than science fiction. Not so. Nissan plans to build a production version within three years, and the basic design has already proved itself in race cars such as the DeltaWing (see "The Fifty Percent Solution," September 2012) and Nissan's ZEOD RC. What's new in this concept car are the all-electric powertrain, with motors inside the rear wheels, and the two-door, three-seat configuration designed for public roads. Most of all, we love that Nissan is brave enough to try and make such a bold idea a reality.

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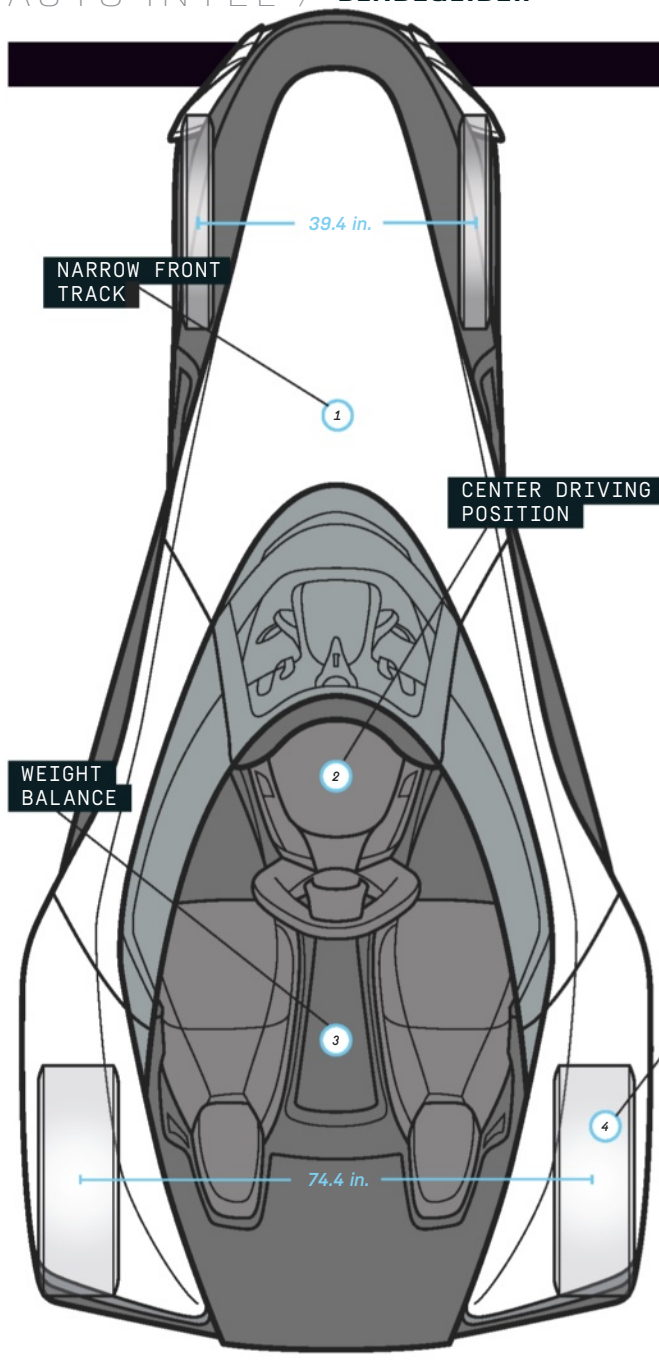
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AUTO INTEL / BLADEGLIDER



1 ***The narrow front track*** drastically reduces drag, which improves range (to about 200 miles, more than double that of the current Nissan Leaf). It also means the front tires follow a closer arc through a corner, eliminating grip-reducing scrub and ensuring the tires share an equal cornering load. The front effectively acts as a single contact point, which keeps it and the rear wheels on the same geometric plane at all times, so the BladeGlider's suspension never has to fight itself over bumps the way a traditional car's does.

2 ***The center driving position*** provides a panoramic view and the sensation of soaring, glider-like, through corners. In the concept car the front seat slides sideways when the doors open to facilitate easier access to the rear seats.

3 ***Weight balance*** is crucial to the BladeGlider's handling. About 30 percent of the weight is on the front wheels, and the center of gravity is close to the rear axle, just behind the driver's seat. This makes the back end act as a stabilizing force, like a boat's keel, and allows the light front to change direction with ease.

4 ***Tire size*** is matched to weight distribution, with 100/80-17 tires in front and 285/35-19 tires in the rear. This maximizes the grip of each tire and ensures neutral handling.



It's tough to accept that wider isn't always better. To understand this, we visited Nissan's Arizona Proving Grounds and drove a proof-of-concept test mule in the form of a modified Ariel Atom. Compared with it, the unaltered Atom we also drove felt nervous and unbalanced. It's not, but the modified car is just that much more responsive and stable. Data confirm the narrow car is better, with a 10 percent boost in lateral grip.

ILLUSTRATION BY **PHIL LAUGHLIN**

ICONS BY **MARTIN LAKSMAN**

SECOND ANNUAL

CinemaTech Awards

NO STATUE, NO CEREMONY—JUST FILM-GEEK KUDOS TO THE YEAR'S BEST SCI-TECH MOVIES.

BY ADAM SAVAGE



Making movies has always been the most technology-intensive of art forms. It takes a small army of artisans to convince us that an actor in a mirrored box is tumbling through space, or that two humans with a mind-melding brain link are controlling a 250-foot-high robot.

We continue Pop-Mech's century-long coverage of the film industry's modelmakers, FX artists, and other specialists with our second annual roundup of outstanding sci-tech achievements. Our panel of experts debated the merits of contenders (very little blood was spilled), tallied the votes, and selected winners in categories that appeal to the film geek in all of us.



Was there another choice? Alfonso Cuarón's story of two astronauts' incredible battle for survival 220 miles above Earth is intense, fresh, and so groundbreaking in its storytelling that it's hard to think of another effects-heavy film with such impact. It's a simple story perfectly told; the drama is never overshadowed by the stunning effects. Cuarón has reset the bar for what's possible with digital environments and 3D, all while keeping his actors' mesmerizing performances front and center. It's an astonishing achievement.

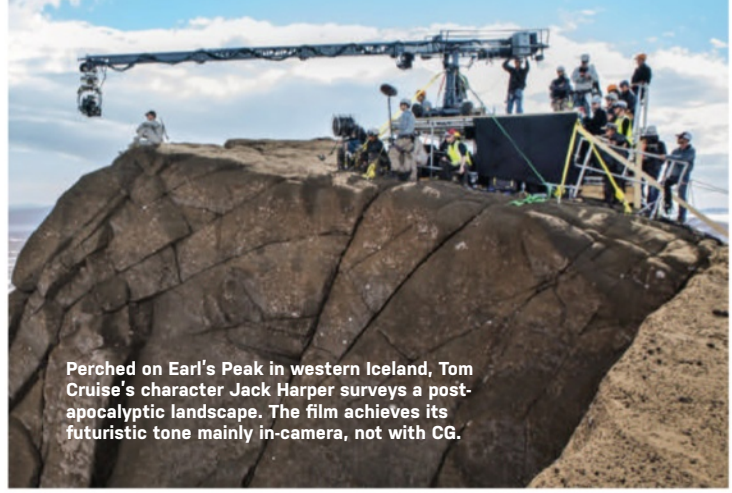
PHOTOGRAPHS BY GETTY IMAGES (SAVAGE, TICKETS, POPCORN)



BEST ALTERNATE UNIVERSE

OBLIVION

Although the plot won't survive serious scrutiny (incredible coincidences, strange decisions made by most of the characters, including the aliens), Tom Cruise's character, Jack Harper, inhabits a compelling and beautiful (if lonely) post-apocalypse Earth. To achieve his vision, director Joseph Kosinski used some of the oldest of old-school film techniques. Much of the action between Cruise and his lover–coworker (played wonderfully by Andrea Riseborough) takes place in a glass house with jaw-dropping views above the clouds. Nearly all of it was realized without any CG whatsoever. FX supervisor Björn Mayer shot plates of clouds and landscape from atop Hawaii's Haleakalā volcano. Instead of compositing these images onto a green screen to be filmed on set, Kosinski projected the cloud plates through the actual set, a process called front projection. It's not only cheaper than CG, it looks better, and it eliminated nearly 500 effects shots. Stanley Kubrick used the same technique in 1968 for his Dawn of Man sequence in *2001: A Space Odyssey*.



Perched on Earl's Peak in western Iceland, Tom Cruise's character Jack Harper surveys a post-apocalyptic landscape. The film achieves its futuristic tone mainly in-camera, not with CG.

BEST GADGETS

ELYSIUM

Nobody beats Neill Blomkamp when it comes to weaving a believable reality. *District 9* seemed so grounded in its time and place as to feel like a documentary about the future. *Elysium,* his post-societal-collapse commentary on our current political situation, is that, only more so: the flying packhorse of a military transport from which the villain Kruger hunts Matt Damon, whose character (above) has an exoskeleton bolted to his dying frame; the search drones that Kruger calls his "girls"; and my favorite piece of conceived future-tech, a Bugatti spaceship, with sleek lines and a leather interior.



SHOESTRING AWARD

EUROPA REPORT

Sebastián Cordero's first English-language feature consists of "found footage" beamed from a doomed mission to one of Jupiter's moons. With excellent performances and convincing sets and effects, it's a terrific example of a smart director spending wisely.

PANEL OF EXPERTS

✪ **ADAM SAVAGE** cohost, *MythBusters;* PM contributing editor; movie-prop-maker ✪ **ANNE THOMPSON** editor-in-chief, Thompson on Hollywood blog; editor-at-large, Indiewire ✪ **BILL DESOWITZ** editor-in-chief, Immersed in Movies blog ✪ **JIM MEIGS** PM editor-in-chief ✪ **DAVID DUNBAR** PM executive editor



BEST STUNT

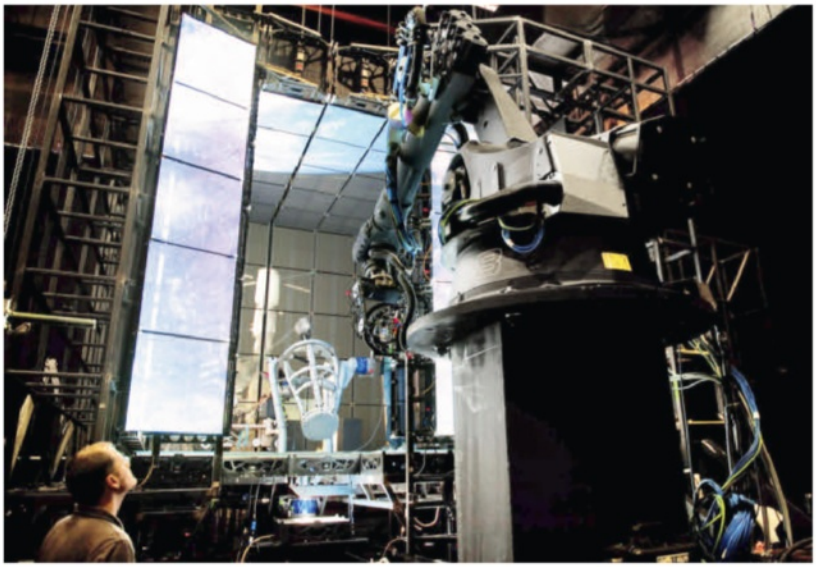
CAPTAIN PHILLIPS

In a year crowded with great stunt work, the standout was also the most real. Director Paul Greengrass hired Somali Americans to portray pirates boarding a 600-foot container ship from a 12-foot skiff. Stunt coordinator Rob Inch trained them to perform most of the film's stunts—an incredible achievement considering none had ever taken an acting class.

BEST DIGITAL EFFECTS

GRAVITY

This is the rare film that utilizes digital effects solely to advance the story. The 3D is immersive yet subtle; the effects are jaw-dropping. Yet what you remember most is Sandra Bullock's brilliant performance as Dr. Ryan Stone. To capture it to the last detail, director Alfonso Cuarón and his team developed a new paradigm for marrying the digital and the real. The centerpiece invention was a 9-foot light box (top, right) lined on the inside with display surfaces. Bullock was strapped into a birdcage-like device and filmed with a robotic camera for up to 9 hours at a stretch, all so the light on her face would perfectly match the previsualized digital action of her character. Hard work, but worth it: The effects keep our eyes on the human element and then take us for the ride of our lives.



BEST EXPLOSION

IRON MAN 3



The choice of real-life bad boy Robert Downey Jr. to play comic-book bad boy Tony Stark signaled early on that the Iron Man franchise was going to play on multiple levels of our cultural consciousness. The first set piece of Shane Black's *Iron Man 3,* the destruction of Stark's mansion perched high above the Pacific, fits right into this program. The breathtaking scene luxuriates in the decimation of Stark's monument to engineering and self-obsession. Black's camera is ever-moving, bringing us complex carnage from every possible angle yet never abandoning us in space, as Tony saves both love-interest Pepper Potts (Gwyneth Paltrow) and himself with the same prototype suit, though Tony ends up a bit worse for wear. Not as bad as his house, though.





COOLEST VEHICLES

PACIFIC RIM

This year's winners have arms and legs (and are 25 stories tall). Two humans inside do all the thinking, and director Guillermo del Toro supplies the heart. In *Pacific Rim,* del Toro resuscitates the giant fighting robot genre with a vengeance. A rift deep in the Pacific Ocean has birthed the Kaiju, monsters from another dimension bent on destroying the human race. Humanity's last-ditch effort to save itself is to build robots called Jaegers (left) that fight the Kaiju hand-to-hand in battles that are a huge level up for the genre. With John Knoll and the geniuses at ILM, del Toro has crafted a love letter to the monster movies of his youth, while also delivering epically badass fistfights. The Jaegers feel anchored in a reality sorely missing from the Godzillas we grew up with.

BEST MAKEUP

RUSH

In Ron Howard's terrific retelling of the auto-racing rivalry between arrogant Austrian Niki Lauda (played by Daniel Brühl, in hat) and playboy Englishman James Hunt (Chris Hemsworth), Lauda is horribly burned in a track accident. Oscar-winner Mark Coulier (with Brühl) created four sets of prosthetic makeup—one for each stage of Lauda's recovery. In a pivotal, cringe-worthy scene, Lauda shoves his helmet onto his raw, scarred head—he simply must keep racing. Post-accident, Lauda is still prickly, but we understand and forgive him. In the end, the thing that makes him hard to look at—his burned, twisted face—is the thing that helps us see him more clearly.



VISIONARY AWARD

ALFONSO CUARÓN

I know, *Gravity Gravity Gravity.* But the film has engendered a new way of thinking about the marriage of digital effects and performance. Cuarón's innovations and inventions will affect how films are made far into the future. That's visionary.

ILLUSTRATION BY **MACKENZIE SCHUBERT**

SURVIVAL • BY KALEE THOMPSON

Troubled Waters

CRUISE LINES HAVE STUMBLED BADLY OVER SAFETY. HERE'S WHAT THEY NEED TO DO.

For the past three decades cruising has been the fastest-growing segment of the travel industry. Eleven new ships were christened last year, and almost 21 million people went on a cruise. Statistically, cruising is relatively safe, but recent failures in seamanship, emergency response, and engineering should sound an alarm. Introduce bad weather or remote surroundings into the equation and an incident like the *Costa Concordia* shipwreck, which made international headlines two years ago, could result in hundreds of deaths.

Compared with other areas where technology and human behavior impact passenger safety—notably, aviation—the cruise industry is poorly regulated. It has no clear equivalent of the Federal Aviation Administration, which has a broad mandate to ensure air safety. The U.S. Coast Guard conducts prescheduled, biannual inspections of ships that embark passengers at U.S. ports, but most cruise ships are registered, or flagged, overseas, and critics charge that regulations are poorly enforced. Cruise lines have started instituting reforms, but more needs to be done.

THE PROBLEM

Crew Incompetence

The January 2012 grounding of the Carnival-owned megaship *Costa Concordia* left 32 dead, 157 injured, and a hulking, disintegrating eyesore beached like a whale off the coast of Tuscany, Italy. It started with ego: Capt. Francesco Schettino swung the ship and its 4229 passengers and crew close to shore on an unsanctioned "salute" to the island of Giglio. The vessel hit submerged rocks, which ripped a nearly 200-foot gash in the hull.

The crew never contacted rescue authorities, who found out about the accident from relatives of panicked passengers. And the abandon-ship order didn't come until 10:54 pm, more than an hour after the collision. The captain himself had already escaped the foundering vessel. "You've abandoned ship!? Get the [expletive] on board!" Italian coast guard captain Gregorio De Falco bellowed when he finally reached Schettino by phone.

The crew didn't perform much better: The industry standard for the evacuation of a vessel is 30 minutes, but hours into the incident there were still dozens of passengers on board.

Given the astounding incompetence displayed during the tragedy, it was largely luck that casualties weren't higher. "The *Concordia* basically tipped over within swim-



ming distance of shore," says Walt Nadolny, chair of the department of marine transportation at New York's SUNY Maritime College. In fact, some passengers did swim to safety. "It would have played out totally differently" in tougher conditions, he says. If the 3780-passenger *Costa Pacifica,* a sister ship to the *Concordia,* had struck a rock on the remote northern coast of Norway, where it travels each summer, passengers would have faced 48 F seas and a lengthy wait for help.

THE SOLUTION In response to the *Concordia* debacle, the Cruise Lines International Association (CLIA)—an industry group whose 26 members represent all of the major cruise companies—ordered a broad safety review led by outside experts, including former heads of the U.S. National Transportation Safety Board and the European Maritime Safety Agency. The effort resulted in 10 new rules to improve crew communication and training. For instance, all bridge officers are to be thoroughly briefed on the passage plan, which includes every detail of a vessel's route; visitors are prohibited from the bridge during critical times; and a lifeboat is to be filled to capacity with crew members during a training drill at least every six months.

It remains to be seen how closely the new rules will be followed; compliance is essentially voluntary. Meanwhile, government oversight is weak. Carnival, which owns 10 lines and controls half of the world cruise market with more than 100 ships, is headquartered in Florida. But the majority of the company's ships—including all of the Carnival-branded vessels—are flagged either in the Bahamas, Panama, or Bermuda. Bill Doherty, a retired safety manager for Norwegian Cruise Line, one of the few big lines not owned by Carnival, is among a number of experts who call these flags of convenience, where labor laws and other regulations are relatively lax.





The *Costa Concordia* shipwreck (top) killed 32; blame fell on the ship's captain, Francesco Schettino (above), who was put on trial for manslaughter last year.

THE PROBLEM

Breakdowns and Blackouts

In February 2013 the *Carnival Triumph* was 150 miles off the coast of the Yucatán Peninsula in the Gulf of Mexico when a fuel line leak led to a fire in the aft engine room. It quickly knocked out power to the ship's six diesel–electric engines, which provide electrical power as well as propulsion. The backup diesel generator could run emergency lights but not the ship's hotel load, which includes lighting and plumbing in the cabins. While the company worked to secure a tow back to port in Mobile, Ala., more than 4000 passengers spent five days in discomfort and squalor as toilets overflowed and hot buffets were replaced with canned food.

Such incidents are surprisingly common. A similar fire in 2010 left passengers on board the *Carnival Splendor* without power off the Pacific coast of Mexico. In March 2013 the *Carnival Elation* experienced a steering problem on the Mississippi River and required a tug escort. Just days later the *Carnival Dream* suffered power and plumbing problems as the result of a generator malfunction while at port in St. Maarten.

None of these incidents resulted in loss of life, but the outcome could have been far different. What if a tropical storm had developed while the *Triumph* floated in the Gulf without steering or propulsion? What if a cruise ship lost power during bad weather in Alaska's remote Inside Passage? Either scenario could turn misfortune into catastrophe.

THE SOLUTION Television commercials for Royal Caribbean's huge Oasis-class ships—which can carry close to 8500 passengers and crew—make Walt Nadolny cringe. "I think, oh, my God, that's not a ship, that's a city. What happens when the power goes out? Is there enough backup to run the galleys and the refrigeration and the sewage treatment plant?" An international maritime standard called Safe Return to Port, which went into effect in 2010, requires that new ships include backup systems that would allow a vessel to limp back to shore in the event of a fire or other emergency. But given the 30-year life span of the typical cruise ship, an aggressive plan to retrofit existing ships is needed. Carnival is mak-

PHOTOGRAPHS BY GETTY IMAGES

ing progress in this area. In April 2013 the company hired a new vice president of technical operations, a former Coast Guard commander named Mark Jackson, and launched a comprehensive upgrade of its 24 Carnival-brand ships—the line that has experienced the most mishaps in recent years. Jackson ordered engineers to reroute miles of cable on each ship to reduce the risk that a fire in one engine room could take out power to the entire ship. Fire suppression is being improved by adding a 24-hour patrol dedicated to scanning for oil and fuel leaks—standard procedure on military ships. The number of nozzles in engine-room sprinkler systems that could be operated at one time is being increased from 30 to 250, and the company is adding another line of backup generators, capable of carrying a portion of the hotel load. "If the *Triumph* incident had happened today," Jackson says, "the detection system would have identified the leak sooner, automatically released the high fog [sprinkler system], and no fire would have occurred." The upgrade project will cost an estimated $300 million.

THE PROBLEM

Poor Passenger Training

International law calls for passengers to receive a safety briefing within 24 hours of a ship leaving port, but that can be too late. About 700 of the *Costa Concordia*'s 3206 passengers had boarded just a couple of hours before the accident; their safety briefing was scheduled for the next day. When things went bad, passengers had no idea where to go or what to do. But the timing of drills isn't the only issue that needs to be addressed. Mike Inman, the vice president of safety for Holland America, another large cruise line owned by Carnival, says that passenger attendance at muster drills hasn't always been enforced. "Holland America was one of the first lines to make it mandatory, and we have disembarked people who did not attend," he says. (Even before the *Concordia* wreck, Holland America held drills before its ships left port.)

THE SOLUTION Since February 2012 all CLIA cruise lines have pledged to conduct passenger muster drills before leaving port. Technology can help too. In October 2013 Danish safety-equipment company Viking announced the creation of a self-propelled, inflatable raft that holds 200 people and has a chute-like system to ease boarding for children, the elderly, and the injured. The LifeCraft could be on ships within two years; such advances could save lives. "How you get the person in the life raft is the most important part," Nadolny says. "Lifeboat injuries are probably the biggest killer of crew out there. It's a fairly complicated arrangement for lifting and lowering the boat, and if it's not done just right, well, the boat drops and everybody in the boat gets killed." That's what happened last year in Spain's Canary Islands during a drill on a cruise ship called the *Thomson Majesty*. Cables snapped, killing five crew members and injuring three more.

THE PROBLEM

Security Holes

Every few weeks someone goes overboard on a cruise ship. Most of those are likely suicides. Other incidents are accidents, often fueled by free-flowing alcohol. An unknown number are murders that will never be solved. Onboard crime is often slow to be reported and is poorly investigated. The reason is that while many ships are the size of a small town, they don't operate like any well-governed municipality on land. "Look at a cruise ship as a city. The captain acts as mayor. What you don't have is a police force," says Kendall Carver, founder of the nonprofit International Cruise Victims Association.

In 2004 his daughter Merrian vanished from a Royal Caribbean cruise in Alaska. Though a steward informed the captain that she hadn't been in her room for five days, no attempt was made to look for her, and the cruise line never reported her missing. Since then Carver has lobbied ship owners to raise railing heights, install cameras and sensing devices that would detect man-overboard accidents, and ensure that alleged crimes are



Innovation in life-raft design can help save lives in future emergencies. The Viking LifeCraft (below) has a chute system to make it easier for passengers to board.

promptly and thoroughly investigated.

In 2010 Carver's group won a seeming victory: Congress passed the Cruise Vessel Security and Safety Act, a law aimed at protecting passengers' rights on any ship that docks in the United States. But the law has proved to be a disappointment.

"We look at it as a feel-good piece of legislation," says Doherty, the retired safety manager. "There are no real penalties for shipowners for violations." Carver cites several major problems. First, the original language of the bill would have required the Coast Guard to maintain online listings of all crimes reported on each ship. But at the last minute it was changed to include only crimes that had been investigated and closed by the FBI. "Instead of reporting hundreds of crimes, 15 or 16 crimes are all that's being reported," Carver says. In addition, he says, cruise lines are failing to follow the law's mandate to inform victims that they can report crimes directly to the FBI.

THE SOLUTION The 2010 Safety Act requires cruise ships to install systems that recognize when someone has jumped, fallen, or been pushed off a ship, if that technology is available. Several companies, including Virginia's Seafaring Security Services and Radio Zeeland, based in Florida, make sensing systems designed to distinguish a body-size mass from anything else—beer cans, beach balls, deck chairs—that drops overboard. The systems can sound an alarm on the bridge, rewind video footage to several seconds before the fall, and record the coordinates so that the crew can launch an immediate rescue. The companies say their own testing shows their systems are reliable, but Carnival director of maritime security Barry Marushi disagrees. "We're looking for a 95 percent detection rate," says Marushi. He says that seabirds can cause false alarms and that the sensors cannot stand up to prolonged exposure to sun, salt, and wave action. "As it stands right now, it has not met those standards that we set."

To resolve this impasse, the industry should fund testing to determine whether the systems are ready now—and push the technology ahead if not. Meanwhile, many ships do not even have video coverage that would reveal a man-overboard accident, leaving agonized families never knowing exactly what happened to a vanished loved one.

None of the problems the cruise industry faces are intractable. Rigorous crew training, better life-raft technology, man-overboard detectors, improved fire-suppression systems—these are all manageable goals. It's up to the cruise ship industry to push harder to fix its problems. And it may be time for passengers to take more responsibility for their own safety, regarding ships as more like airplanes and less like resorts, despite the buffets and swimming pools. Because there's one big difference: Hotels can't sink. **PopMech**

Know Before You Go

THE APPEAL OF A CRUISE VACATION IS THAT ONCE YOU'RE BOOKED, YOU DON'T HAVE TO THINK ABOUT A THING. IT'S WISE TO MAKE AN EXCEPTION WHEN IT COMES TO YOUR FAMILY'S PERSONAL SAFETY.



1. ***Select a safe ship.***

Vessels that have come into service since 2010 meet stringent international Safe Return to Port requirements to ensure that an engine-room fire doesn't knock out power to the entire vessel. For information on sanitation you can check the Centers for Disease Control's report card on cruise ships at cdc.gov/nceh/vsp/.

2. ***Take drills seriously.***

In an emergency you want to know where to muster, or gather; where to find spare life jackets; how to interpret alarms; and how to enter a lifeboat. Always know where you are on the ship—and pay attention to fire alarms. Most serious shipboard incidents are the result of fires.

3. ***Supervise children.***

Cruise ships generally do not employ lifeguards: In October 2013 a 6-year-old Florida boy drowned in a swimming pool during a Caribbean cruise on the *Carnival Victory*. A few months earlier a 4-year-old had suffered severe brain damage after a near-drowning accident on a Disney ship.

4. ***And teenagers.***

According to the International Cruise Victims Association, sexual assault is the most common crime reported on cruise ships, and many of the victims are teenagers. For more information visit the organization's website, internationalcruisevictims.org.

5. ***Don't drink alone.***

Alcohol flows free and heavy on a lot of ships—that's part of the appeal for many passengers. But being alone and intoxicated are both risk factors for man-overboard incidents. You can consult cruisejunkie.com to learn more about man-overboard accidents.

6. ***Know your rights.***

When you step on board a cruise ship, you are effectively entering a foreign country; U.S. laws do not apply. But, thanks to the 2010 Cruise Vessel Security and Safety Act, crime victims can go directly to the FBI for help. Call 202-324-3000 to report a crime.

ILLUSTRATION BY MACKENZIE SCHUBERT

PHOTOGRAPHS BY **BRENT HUMPHREYS**

LAUNCH • BY CHRIS RAYMOND

The Design-It-Yourself Revolution

HOW A TINY TEXAS GUITAR MAKER IS BRINGING MASS CUSTOMIZATION TO THE MUSIC BUSINESS.



Moniker Guitars cofounder Kevin Tully builds one-of-a-kind instruments for people with a knack for self-expression.

Kevin Tully was in Syracuse, N.Y., studying for the bar exam when a friend came pedaling up to his apartment on a bicycle. Not just any bicycle but a one-of-a-kind machine she herself had created on a hip, design-it-yourself website owned by Republic Bike. "She went online and picked out all the colors and parts," he says. "She was really enthusiastic about the bike because it represented her sense of style."

As a lifelong guitar player, Tully identified with that sense of pride. He was no Jimi Hendrix, but the two instruments in his home ranked among his most prized possessions. How great would it be, he wondered, if they could truly reflect his personal taste?

And so, over Thanksgiving in 2011, Tully approached his high school friend Dave Barry, a fellow guitar enthusiast, with the idea of launching a business. "Your guitar is kind of an

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extension of yourself, and guitar players are creative by nature," Barry says. "We wanted to give people the opportunity to create their own guitar."

Five months later the duo unveiled Moniker Guitars using $25,000 in seed funding from the business incubator at Barry's alma mater, Northeastern University. The company now employs six people and operates out of a shared work space in Austin, Texas, turning out a dozen or so electric guitars a week. If you want a cherry-red model with a crisp, white racing stripe, Moniker will make it for you. Zebra stripes? That too. Polka dots? Yep. Even logos, photos, and type. The company offers three body styles, five stains, 17 paint colors, and limitless graphic options.

Custom-made instruments are nothing new, but for years few musicians—beyond those with platinum record sales—had the money or the pull to create a signature style. Now, using online design tools and advanced manufacturing techniques, Moniker has figured out how to produce high-quality instruments with artistic touches for $850 to $1250—roughly what one would pay for a generic model in a store.

Moniker has joined a growing movement known as mass customization. In an era when technology has made it possible to personalize almost anything, examples of such items abound: sneakers, cellphone cases, Scion cars, messenger bags, toolboxes, T-shirts, couches, bed linens, coffee mugs, drapes, boots, chocolate bars, and M&M's. In his book, *Custom Nation,* Anthony Flynn argues that this shift in product development is so sweeping that it will one day rival the impact of the industrial revolution. Flynn witnessed the power of the trend after he founded YouBar, a company that enables consumers to create their own energy bars. He was trying to target people with food allergies and other health issues, but the audience turned out to be much broader. Young consumers have come to expect one-of-a-kind experiences, he says: on-demand TV and movies, plus tailored news feeds (Facebook and Twitter), music-streaming sites (Pandora and Spotify), and dating services (Match.com). With the advance of 3D printers, there will soon be no end to what people can personalize.

Kent Deverell is the CEO of the Web development company Fluid, which has created customization sites—aka configurators—for The North Face, Reebok, L.L.Bean, Brooks Brothers, and Oakley sunglasses. "It's probably the fastest-growing area of our business," he says. For today's retailers, he explains, personalized products are an ideal way to compete with Amazon, the king of bargains and selection. "People who buy customized products are your best customers," Deverell says. "They engage with your brand, they're willing to pay more,



In addition to 17 colors and five stains, Moniker gives customers the option to add text and personalized graphics. The company's low-VOC, water-based paint is also used by Ferrari and Lamborghini.



Kevin Tully (below, left) and Dave Barry craft the bodies of Moniker guitars from lightweight alder, known for striking a pleasant balance between warm and bright tones.

and they have a higher level of satisfaction. If I buy a customized shoe from Nike, I'm 45 percent more likely to recommend that brand to another person than someone who just bought a shoe off the shelf."

And as startups such as Moniker attest, it's far easier to enter the market these days than it was in 1999, when Nike reportedly spent $30 million to develop the configurator for its groundbreaking NIKEiD program. Tully says he built Moniker's configurator for about $10,000 with the help of a friend and a freelance developer. It took roughly three months of round-the-clock work on Photoshop to get the images just right. "Our main goal was to keep the site as clean and simple as possible," Tully says. "If my mother couldn't use it, we were doing something wrong."

Streamlining production was the next challenge. "When we started, we realized that we live in an instant-gratification society," Barry says. "People want things now. We had to figure out a way to produce high-quality guitars with relatively fast turnaround."

A CNC mill allowed the team to precisely replicate each body, including the cavities in Moniker's semi-hollow models. Most guitar makers prime the wood—in this case alder—with a nitrocellulose clear coat that can take a month or more to dry. After looking around, Moniker discovered a clear polyester resin manufactured by Simtec that cures in minutes under ultraviolet light. "You have to wear a protective suit, which is awesome in the summer when it's 110 degrees outside," Tully says.

Instead of standard solvent-based spray paints, which are not only slow to dry but can run afoul of environmental regulations, the company uses a water-based paint low in volatile organic compounds, manufactured by PPG Industries. (Ferrari and Lamborghini have also adopted it.) Moniker also uses advanced printing techniques, including a vinyl plotter that makes spray-paint stencils from vector files built in Adobe Illustrator, to create type and graphics. If pressed, Tully's team could probably assemble a guitar in 24 hours, though standard delivery is four weeks.

It's still too soon to predict Moniker's success—Tully will not divulge sales figures—but the early feedback is promising. The company's guitars have been featured on MSNBC and showcased at the South by Southwest and Bonnaroo music festivals. During a 2013 Kickstarter campaign, Moniker raised $60,000 from 155 backers in a single month. And Tully's guitars are now popping up in the hands of artists on the Austin music scene. Tyler Temple of American Dischord even had the company's logo tattooed on his hand.



One author claims the mass-customization movement will someday rival the impact of the industrial revolution.

Kyle Bailey, a guitar aficionado who runs an online marketing company in Austin, has visited Moniker's workshop to test out the wares. In an online review, he praised its pickups, particularly the top-of-the-line Seymour Duncan options—noting the guitars' string-to-string detail. "That's one of the things that makes high-end Les Paul guitars sound so clean," he says. "You can hear each string very clearly. Moniker's electronics achieve that. They're very responsive."

Tully would be happy simply to engage his version of the guitar hero. "I don't mean U2 or Led Zeppelin," he says. "I mean working musicians who are passionate about what they do but have to grind it out to make a living." And it's not all about advanced technology. "The end goal is to have the guitars look classic," Tully says. "Not like something from the future but like what guitar traditionalists would appreciate." **PopMech**

ILLUSTRATION BY **SACHIN TENG**

ENERGY • BY JAMES B. MEIGS



The Case for Biomass

THE LAW FAVORS SOLAR PANELS—BUT WOODSTOVES DESERVE EQUAL TREATMENT.

Imagine two homeowners: One is a wealthy investor building a vacation house near Lake Tahoe in California. The other owns a middle-class home outside Burlington, Vt. Both are interested in keeping their energy costs under control—and helping the environment while they're at it. The owner of the Tahoe ski palace installs an expensive solar-energy system to power his lights and appliances, covering his roof with photovoltaic panels. (He uses natural gas for heat.) The Vermonter invests in a clean-burning wood-pellet stove, cutting his consumption of heating oil by about 80 percent.

Our Tahoe homeowner enjoys the virtuous glow of being seen as an alternative-energy pioneer. He also enjoys something else: Under the Energy Policy Act of 2005, he is entitled to a tax credit equal to 30 percent of the cost of his system, including installation. Let's say Mr. Tahoe installed a 6-kilowatt PV system at a cost of about $23,000. His federal tax credit works out to nearly $7000, and the state of California kicks in additional incentives.

Our Vermont homeowner isn't so lucky. The IRS offers only a 10 percent credit on biomass heating systems like his stove. The credit doesn't include installation costs, and the total is capped at $300. That's a grudging level of support—yet the pellet stove may be doing more than the solar array to help the environment.

The systems are tough to compare: It's electricity versus heat, and removing reliance on a distant power plant rather than an oil burner in the basement. But to get a rough idea, we can calculate the energy savings from both systems using British thermal units, or Btu. The Vermont homeowner's system saves about 575 gallons of oil yearly, which is the equivalent of 79 million Btu. The Tahoe system might produce close to 9000 kilowatt-hours of electricity a year—about 30 million Btu.

Even if the energy savings were equivalent, the Vermont system arguably provides more benefits. I don't mean to discount the good things about solar power. But what is the logic behind offering incentives that are 10 or 20 times larger for a solar installation that produces less than half as much clean energy as a basic wood heat system? And the power that a solar system creates isn't automatically greener than the power it replaces. Sometimes solar panels replace electricity generated in high-emissions coal-burning plants, but electricity also comes from hydroelectric, nuclear, or relatively clean-burning natural-gas power plants.

In contrast, all residential oil-burning heaters release carbon that has been locked underground for eons, adding to the net load of greenhouse gases in the atmosphere. Wood isn't like that. A tree pulls carbon out of the air as it grows; when you burn it the CO_2 returns to the atmosphere, where other trees can use it in turn. The same thing would happen if the wood were left in the forest to rot. And it's not like we're short on trees. "A lot of forests in the U.S. are vastly overstocked with fuel," says Steve Marshall, assistant director of cooperative forestry at the U.S. Forest Service. Responsible thinning operations can yield plenty of environmentally friendly fuel.

Closer to home, local woodlots and landscaping operations supply much of the wood currently burned in residential stoves. That's quite a contrast with fossil

fuels, which need to be extracted from the earth and then transported long distances before being used.

You can debate the physics details, but the disparity in U.S. energy laws is hard to justify. "There is a terrible double standard here," says John Ackerly, the president of the Alliance for Green Heat, a pro-wood-heating advocacy group. "Right now, most energy incentives target fairly expensive systems such as solar and geothermal rather than wood-heat technology, which might make more sense for the average American family."

Of course, for woodstoves to make a positive environmental impact, they need to be a lot cleaner. Unfortunately, most of the 10 million households using wood heat in the United States have dirty, out-of-date technology. An inefficient stove can produce as much as 40 grams of unhealthy particulate matter an hour. It doesn't have to be that way. Many modern wood and pellet stoves produce under 1 gram per hour. That's not far from what many oil burners produce. These clean-burning stoves deserve the same kind of incentives solar panels enjoy.

Popular Mechanics recently joined the Alliance for Green Heat on a project called the Wood Stove Decathlon (see "Woodstove Renaissance," page 24). The contest offered cash prizes to teams for devising new stoves that combine efficiency, low emissions, and affordability. The competition attracted established stovemakers, independent inventors, and a team of student engineers from the University of Maryland, who all took their stoves to Washington, D.C., for nearly a week of testing. The top designs featured both established technologies (such as secondary-burn chambers and catalysts to promote cleaner combustion) and exciting new ideas (including tiny thermoelectric generators to power fans controlling airflow).

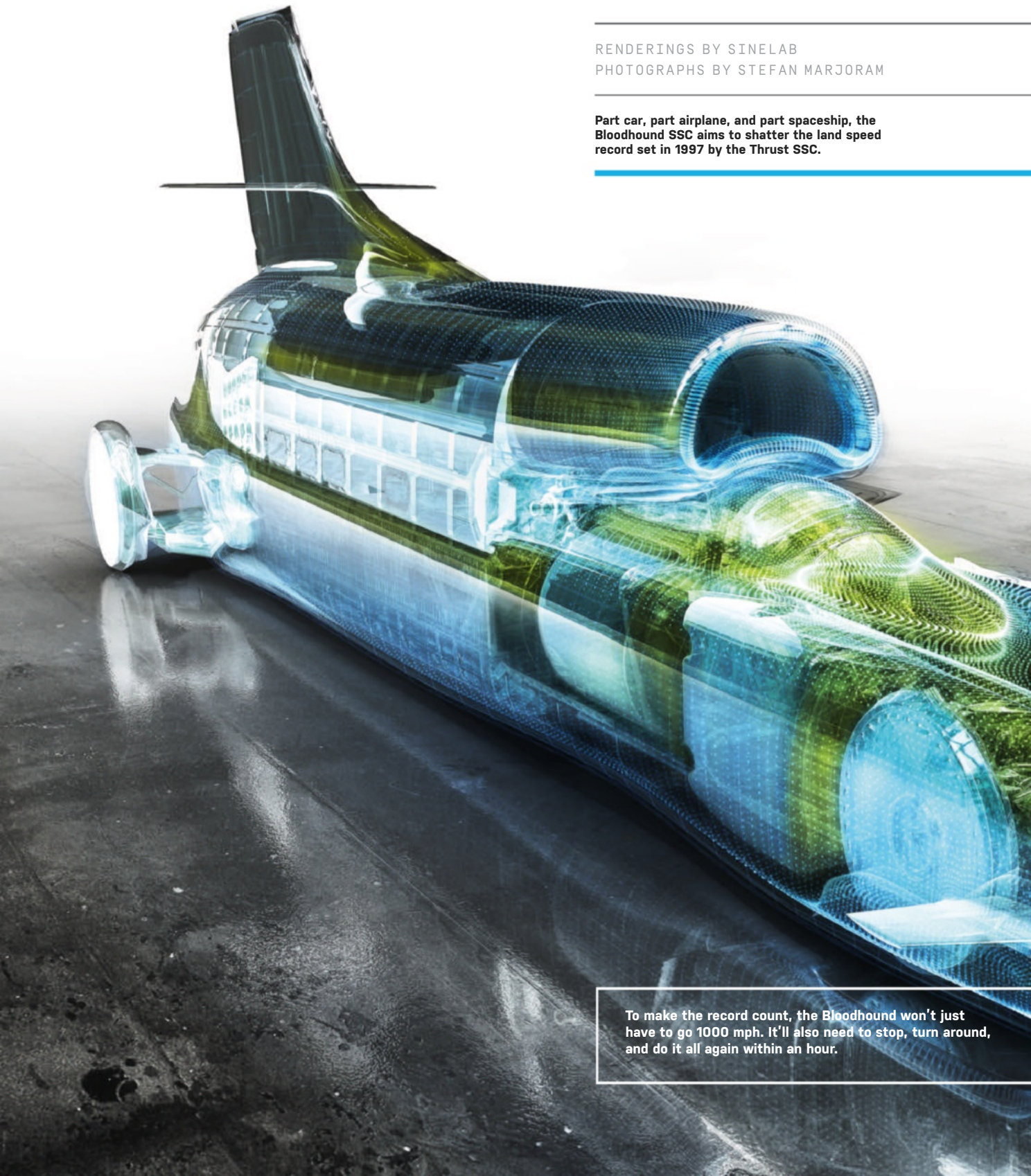
The Decathlon helped prove that the technology is here to make biomass heating much cleaner and more efficient—and that much more progress is possible. Now we need the federal government to catch up by creating a level playing field. Shiny solar panels on million-dollar homes are nice, but clean, affordable woodstoves can do a lot more to improve our energy and carbon-emissions picture. **PopMech**

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BY ANDREW ENGLISH

RENDERINGS BY SINELAB
PHOTOGRAPHS BY STEFAN MARJORAM

Part car, part airplane, and part spaceship, the Bloodhound SSC aims to shatter the land speed record set in 1997 by the Thrust SSC.



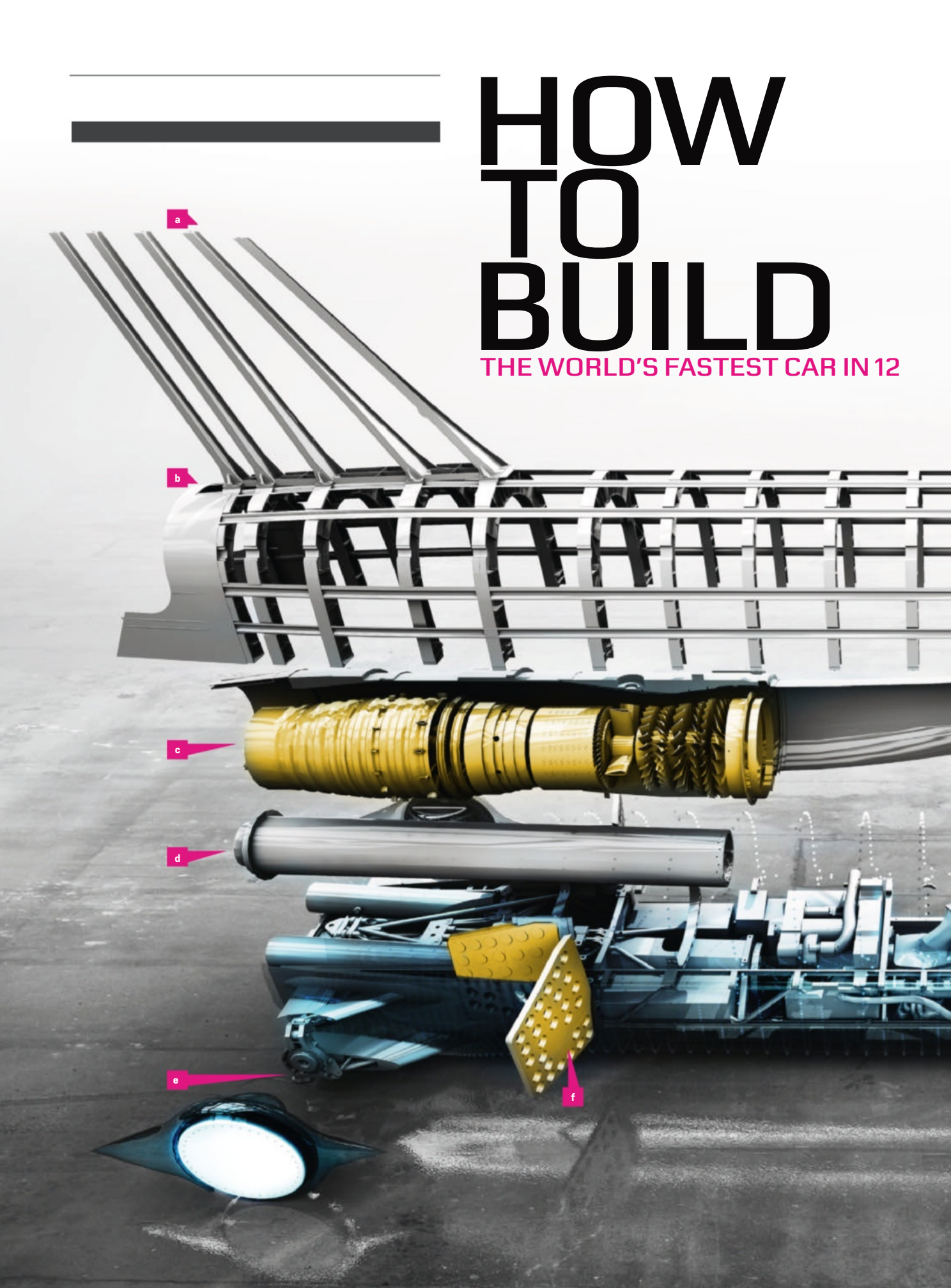
To make the record count, the Bloodhound won't just have to go 1000 mph. It'll also need to stop, turn around, and do it all again within an hour.

THE 1000 MPH CAR DOES NOT EXIST —YET



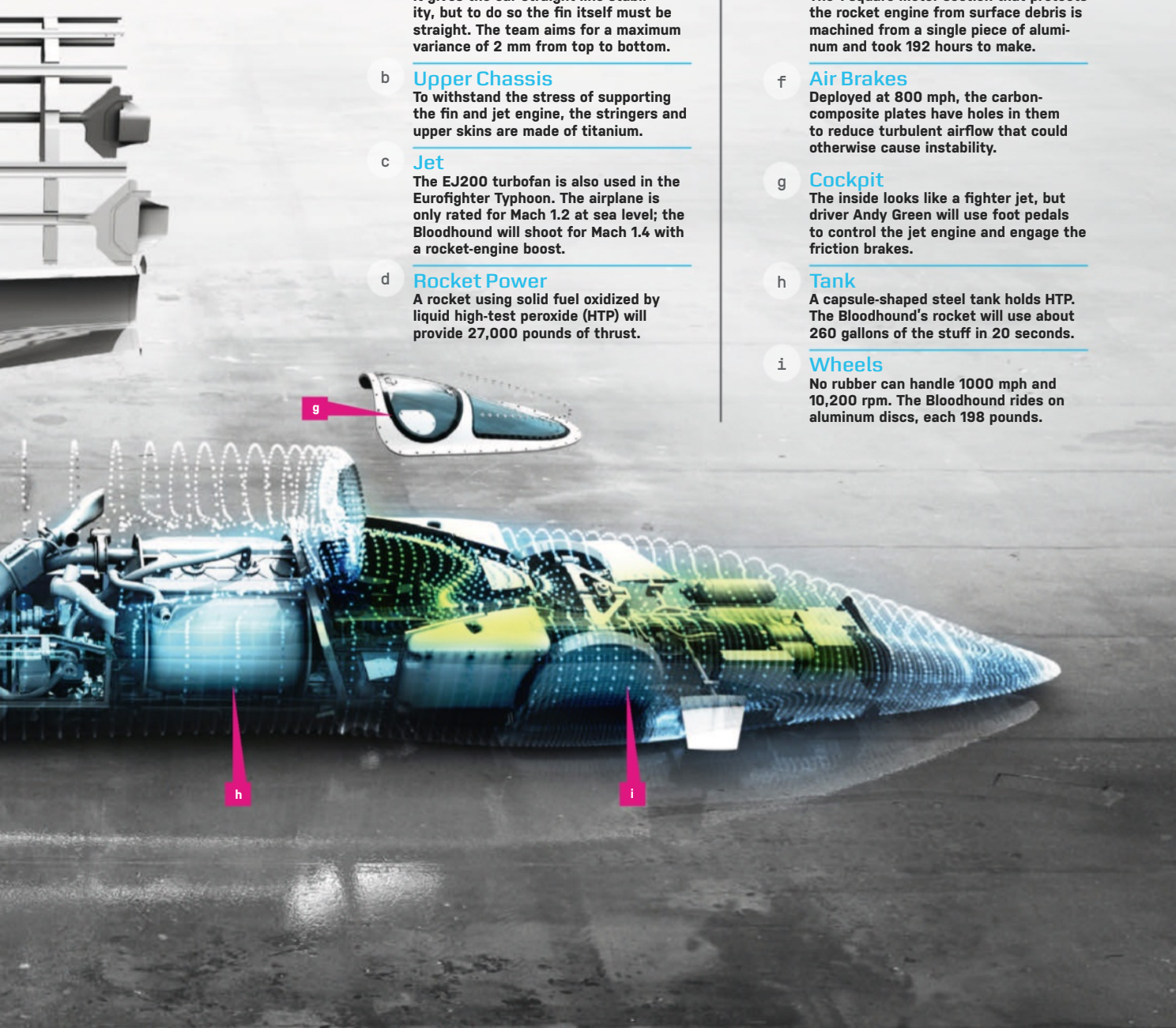
HOW TO BUILD

THE WORLD'S FASTEST CAR IN 12



TORTUOUS STEPS.

1. Break the sound barrier first. On Oct. 15, 1997, high in Nevada's Black Rock Desert, a sonic boom cracked the air as Royal Air Force pilot Andy Green raced past 747 mph, the speed of sound, at the location's 4000-foot elevation and ambient temperature. The Thrust SSC jet car's twin Rolls-Royce Spey turbofans—also used in the F-4 Phantom fighter—produced 40,000 pounds of thrust, pushing the car to 759.333 mph. After 12 years of design, development, fabrication, and testing, meeting the land speed record criteria of the Fédération Internationale de l'Automobile came down to turning around and making a second run within an hour. On the return trip the Thrust SSC broke the sound barrier again, traversing the measured mile at 766.609 mph, for a two-way record of 763.035 mph—and proving that when man battles nature, technology is a mighty weapon. As Green said before the historic run: "Just because it hasn't been done doesn't mean we can't do it."



a **Fin**
It gives the car straight-line stability, but to do so the fin itself must be straight. The team aims for a maximum variance of 2 mm from top to bottom.

b **Upper Chassis**
To withstand the stress of supporting the fin and jet engine, the stringers and upper skins are made of titanium.

c **Jet**
The EJ200 turbofan is also used in the Eurofighter Typhoon. The airplane is only rated for Mach 1.2 at sea level; the Bloodhound will shoot for Mach 1.4 with a rocket-engine boost.

d **Rocket Power**
A rocket using solid fuel oxidized by liquid high-test peroxide (HTP) will provide 27,000 pounds of thrust.

e **Rear Diffuser**
The 1-square-meter section that protects the rocket engine from surface debris is machined from a single piece of aluminum and took 192 hours to make.

f **Air Brakes**
Deployed at 800 mph, the carbon-composite plates have holes in them to reduce turbulent airflow that could otherwise cause instability.

g **Cockpit**
The inside looks like a fighter jet, but driver Andy Green will use foot pedals to control the jet engine and engage the friction brakes.

h **Tank**
A capsule-shaped steel tank holds HTP. The Bloodhound's rocket will use about 260 gallons of the stuff in 20 seconds.

i **Wheels**
No rubber can handle 1000 mph and 10,200 rpm. The Bloodhound rides on aluminum discs, each 198 pounds.

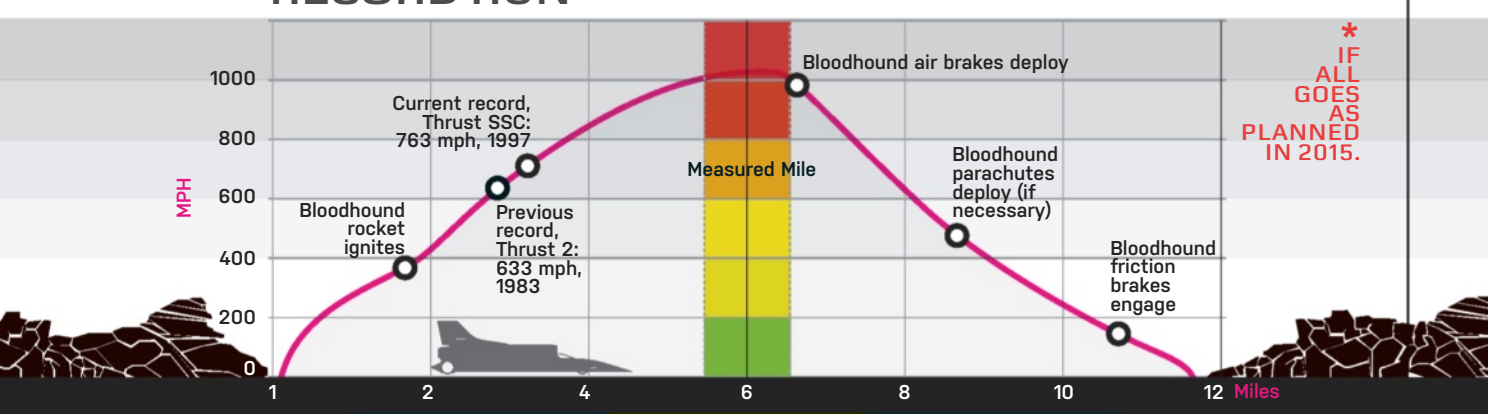
2. Call back your key players. Fast-talking and irrepressible, the Thrust SSC team's leader, Scottish aviation entrepreneur Richard Noble, has a history in the sport. He himself had set the record in 1983, piloting the jet-powered Thrust 2 to 633.468 mph. (He told the press he had done it "for Britain and for the hell of it.") After breaking his own record 14 years later with the Thrust SSC, he retired. But when celebrity adventurer Steve Fossett announced in 2006 that he would pursue a new record, Noble rose to the challenge. Like an impresario reassembling a veteran rock band for one last tour, Noble began recruiting key members from the Thrust SSC team, including Andy Green. He also brought back aerodynamicist and engineer Ron Ayers, now 81, whose experience dates back to his work on Britain's Cold War bomber the Handley Page Victor. (Another previous Ayers project, the Bristol Bloodhound surface-to-air missile, gives the current jet car its name.) Today, Ayers toils away at a desk strewn with laptops, half-drunk cups of tea, and a computational tool most young engineers know as a relic—a slide rule.

Chief engineer Mark Chapman is another longtime associate. He helped design the single-engine aircraft now known as the Kestrel JP10 for Noble's somewhat rocky venture, Farnborough Aircraft. The Bloodhound project requires a diverse range of talents, Chapman says. "The vehicle is part plane, part car, and part spaceship. We need people with a huge breadth of experience." Fossett was killed during a solo flight over California's Sierra Nevada range in late 2007, and his speed-record team disbanded soon after. But by then Noble was committed, fostering his resources and his talent. Now he has them, and some key technologies—namely, CAD and computational fluid dynamics, or CFD—fully deployed. "Thanks to CFD, designers and engineers can take charge," Noble told The Telegraph. "Land speed record attempts are no longer about some maniac with an enormous engine and a tiny car disappearing off into the blue."

3. Learn from your mistakes. During the Thrust SSC's run, video taken from a distance makes the car look as if it's riding on rails. But cockpit audio and video contain an expletive-laden outburst as Green struggles to maintain control, turning hard right and left to counteract dangerous oscillations as the vehicle nears the speed of sound. In this transsonic period the airflow over the car is supersonic in some places, and subsonic in others, which makes the car unstable. "It got a lot calmer after it broke the sound barrier," Green says, betraying no sense of concern. In fact, he was one twitch away from catastrophe. The culprit: unwieldy rear-wheel steering, a design compromise required by the Thrust SSC's tight front end.

4. Embrace failure, then correct for it. Front-wheel steering for the Bloodhound was an easy call (Green insisted), but other configurations require painstaking trial and error. After the project kicked off, in October 2008, the team burned through 13 design iterations in three years. Initially, the heavier jet sat beneath the rocket. But the rocket's thrust from a high position would have pushed down the car's nose; then, after the rocket fuel was spent, eliminating weight and thrust, the possibility of the front end getting airborne would increase. "A nose-up moment at speed would not be

12 MILES OF AWESOME: THE BLOODHOUND'S RECORD RUN*



* IF ALL GOES AS PLANNED IN 2015.

SPEEDING UP
The Bloodhound will reach 1000 mph in the first 5.5 miles, covering that distance in just 55 seconds.

MAKE MY DAY
At 1000 mph, the car would outrun a bullet fired from a .44 Magnum. You know, like the one Dirty Harry carried.

MEASURED MILE
Timing occurs through a 1-mile midcourse section (the colored strip, above). It'll be gone in 3.6 seconds.

TARGET: 1050
The actual peak speed is 1050 mph, to provide a buffer ensuring a 1000-mph average over 2 measured miles.

ROCKET SWAP
At the end of the run, the spent rocket, still hot, will be removed and a new one installed within minutes.





Engineers apply arched supports to the frame of the lower chassis, which will be outfitted with aluminum ribs and sheathed in steel. About 4000 aviation-grade rivets and a special glue are used to secure the metal shell. Richard Noble (left) is the man behind the dream.

good," Noble says.

To improve stability and maintain ground force, the team repositioned the rocket below the jet and made the rear fin bigger. In front, winglets help keep the nose level. At present they're movable, to address the changing forces during the run. But computer-aided movement of the wings introduces a big risk. "What would happen if Andy got the blue screen of death at high speed?" Chapman asks, referring to the visual result when an old Windows operating system freezes. For Green, the analogy would be literal. The goal is to make the winglets static. "With experience, as we begin practice runs, we hope to fix them into place," Chapman says. The fewer things Green deals with while driving, the better.

5. Build it like a fighter jet. The Bloodhound project headquarters is a boxy industrial building on the outskirts of Bristol (fittingly, a hub for England's tech and aviation industries) flanked by builders' supply warehouses and a tile depot. A food truck serves hamburgers in the parking lot. The hangar-style structure is the site of the monthly team meeting as well as where the car's pieces come together. The rear two-thirds of the vehicle resembles a plane, with an aluminum and titanium frame, and an aluminum floor to deflect debris. The rocket engine mounts onto the lower fuselage, and even the titanium and steel skins are load-bearing. Like the F-4 Phantom that Green flew for the RAF, the Bloodhound has an internal air-supply system and fire extinguishers. Unlike that jet, the car has no ejector seat, because ground impact after ejection would be inevitable. "We'd be talking about a near-sea-level Mach 1.4 ejection, so the forces are huge," Chapman says.

6. Get indestructible wheels. The Bloodhound doesn't have tires; it runs on precisely fabricated aluminum discs. A forging process breaks down the crystalline structure of cast aluminum, making it denser and stronger. This requires heating the aluminum to more than 700 degrees Fahrenheit, molding the metal into discs with a 3668-ton

GRAPH BY MARTIN LAKSMAN



An engineer (left) fine-tunes the monocoque, which is fabricated as a single carbon-fiber piece, to precisely fit the driver, Andy Green (below).





Green (above) tests the fit of the 3D-printed prototype of the steering wheel. A perfect match for Green's hands, the finished version was also printed—out of titanium. A display model of the 44-foot-long Bloodhound (above, right) sits in the atrium of the Rolls-Royce headquarters in London. The company's EJ200 jet, part of the car's powerhouse, rests on a rack.

press and then milling the blanks to the finished specs: 198 pounds, 36 inches diameter. The wheels not only have to bear the car's 17,000 pounds but also to hold together while experiencing 50,000 pounds of radial g-forces at 10,200 rpm. That means their shape is as crucial as their strength. Recent testing at Hakskeen Pan revealed that twin-keel-shaped rims like those on the Thrust SSC would break through the site's soft surface, so the Bloodhound will use a rounded wheel profile.

7. Put a rocket on it. The Thrust SSC's 763-mph run provided valuable reference points for the Bloodhound, but gaining an additional 250 mph presents a disproportionately more difficult challenge. Aerodynamic drag increases with the square of speed, which means that there is 1.7 times more drag at 1000 mph than at 763 mph. Even though the speed increase is only 31 percent, 2.3 times more power is required to make up the difference. Ayers calculated that two jet engines wouldn't work for the Bloodhound—the air intakes would produce too much drag, and the engines would be too heavy. Instead, the Bloodhound uses the steady power of a Rolls-Royce EJ200 turbofan producing 20,233 pounds of thrust, while a hybrid rocket provides a 20-second boost. Designed by the Norwegian firm Nammo, which makes stage-separation and acceleration boosters for the European Space Agency's Ariane 5 launch vehicle, the rocket is an ingenious design that burns a solid synthetic-rubber fuel but uses liquid high-test peroxide, or HTP, as the oxidizer. The engine consumes a staggering 260 gallons of HTP in about 20 seconds to achieve peak thrust of 27,000 pounds.

8. Find the right track. Both Thrust SSC and Thrust 2 made their record runs on the flats of Black Rock Desert. But drought and other factors have roughed up that surface, so the team looked elsewhere. Using custom software the Bloodhound team identified 22 sites with a smooth, flat surface 12 miles long and 3 miles wide. After narrowing the list and visiting 14 sites, South Africa's Hakskeen Pan, a dry lakebed, was chosen. But even this, in its natural state, was flawed. So, with the backing of local officials, workers moved about 6000 tons of stones from the proposed track, largely by hand. The stones have been piled up beside the track; removing them is prohibited because the team lacks a mining license. After the run, geologists will sift through the piles for meteorites.



9. Figure how to get from 1050 to 0 mph. If all goes as planned, the Bloodhound will cover the measured mile in 3.6 seconds and reach a top speed of 1050 mph. But to claim the record, the car must turn around and make a second run within an hour. And space is an issue. "You can just run out of desert," Chapman says. The Bloodhound has three means of deceleration: At 800 mph perforated air brakes swing out from the fuselage, two parachutes can deploy at 600 mph if extra slowing is needed, and at 200 mph Green will apply steel friction brakes. But slowing down is just one concern. The idling jet engine will continue to produce heat at the end of the run, which Green must dissipate by steering in a huge arc while slowing to a stop. Whether that's all possible no one knows. "We can't really test that until we get to South Africa," Chapman says. "For a lot of things, the car is the testbed."

10. Pay attention to the little stuff. Dust, for instance. "We're looking at peak flows of over 600 meters per second of dusty air hitting the car—it's worse than a shot blaster," Chapman says. So, steel armors the undercarriage. Surprisingly, there's no need to physically protect the engines from dust. "There isn't enough time for the dust to travel upward the 1.5 meters to the intake," he says.

11. Keep calm and speed on. Green's experience makes him the obvious pick to pilot the Bloodhound. But 20 years ago he wasn't a shoo-in to drive the Thrust SSC. The final eight applicants, all pilots, went through fiendish psychological and coordination tests devised by Roger Green (no relation), professor at the Centre for Human Sciences in Farnborough, England. "The most obvious thing to do was to give them all a sanity test and take the ones who failed," Roger Green joked at the time. Andy Green was not the fastest driver of the bunch, but during trials he showed an almost out-of-body detachment, which allowed him to objectively analyze what was happening at high speed. He is also famously taciturn. Many journalists have tried and failed to goad Green into expressing any sense of excitement or nervousness about driving in excess of 1000 mph. "And there's the extreme vibration and noise and the stress of checking and rechecking the systems," says Roger Green. "Apart from all those things it should be fairly easy."

12. Control what you can, but accept that you can't control all that happens at 1000 mph. One engineer confessed that when the Thrust SSC ran, he felt physically ill for fear of the car failing—because he knew all of the "10,000 things" that could go wrong. When the Bloodhound goes for the record, Chapman says, "We don't really know what it will be like. We're not [even] sure what a safe observation distance will be from a vehicle traveling at Mach 1.4, or how far the shock wave will spread out sideways from the car." Ron Ayers may share some of Chapman's concern when the Bloodhound makes its run. But as the most experienced member of the team, Ayers doesn't see failure as an option, for one simple reason: "Andy Green is a good friend of mine." **PopMech**


MAKERBOT
I used a MakerBot Replicator 2 printer to manufacture a small arsenal of launchable rockets, albeit with varying degrees of flight worthiness.
MakerBot Replicator™2
DESKTOP 3D PRINTER



Getting Started in

3D Printing

BY LEE H. GOLDBERG

PHOTOGRAPHS BY MICHAEL GEORGE

The work I've done on spacecraft got me hooked on 3D printing. When I was an electrical engineer for RCA Astro (now part of Lockheed Martin), I helped design, build, and launch the Mars Observer and other interplanetary probes. Back then I had dreams of building my own spacecraft and rocket engines but was discouraged by how expensive and time-consuming it was to fabricate even the simplest space-grade hardware.

You can imagine, then, how exciting it's been watching aerospace companies put 3D printers to work in screen-to-machine manufacturing systems that dramatically cut the time and cost of printing flight-worthy parts. Considering how quickly once-primitive home-brew machines have evolved, it won't be long before anyone can print parts for airframes and rocket engines. For now, however, I'm content to learn the basics by building model rockets on the

consumer-grade, plastic-spewing 3D printers available today.

The ABCs of 3D Printing

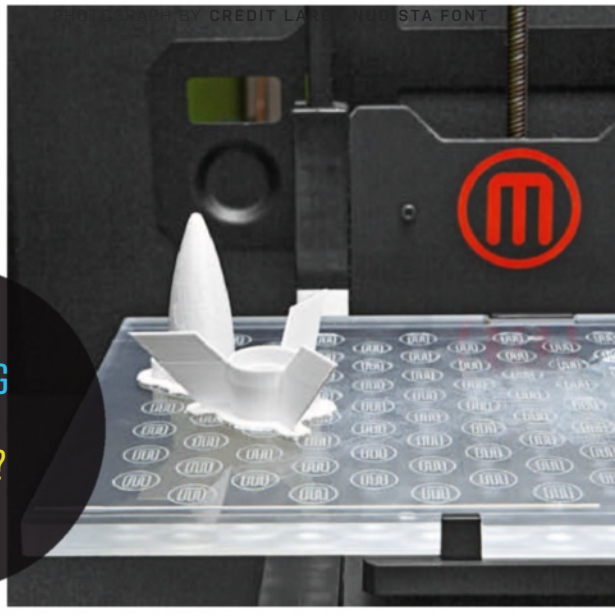
My printed rockets began life as mathematical models—a bit like 3D digital photographs. I could have created my own printable files from scratch using CAD software, but since I even have trouble drawing stick figures with a No. 2 pencil, I decided to work from existing projects instead. I downloaded files for three rockets—each one more challenging than its predecessor—from MakerBot's Thingiverse website, which is a library of more than 100,000 user-submitted designs.

Before investing in my own printer, I decided to get some experience on someone else's. I asked around at my local co-working space, Tigerlabs, in Princeton, N.J., and found a tenant who let me use his MakerBot Replicator 2 in exchange for a couple of the rockets I hoped to make and a generous spool of printer filament (about $50).

3D printers build things by depositing successive layers of material, a process called additive manufacturing. Most use a mechanism that's like a cross between an inkjet printer and a hot-glue gun: A plastic filament feeds into a heated printhead, which dispenses hot goo that quickly cools and hardens. Early homemade printers used replacement line from string trimmers as feedstock, but today's machines run on specially made material.

Those serious about 3D printing use machines that handle all kinds of plastics, most commonly ABS (acrylonitrile butadiene styrene) and PLA (polylactic acid), but also materials such as nylon, fiber-reinforced plastics, and PET (polyethylene terephthalate) derived from recycled soda bottles. ABS is popular because it's strong, inexpensive, and easily modified with tools after printing. On the downside, ABS emerges from the printhead as a thick syrup that flows slowly and shrinks as it cools, making high-precision printing a tricky affair.

I used PLA for my rockets, simply because it was already loaded into the printer I borrowed. PLA is generally more difficult to work with than ABS, but it offers greater strength and print accuracy. It sets faster than ABS, so it can deposit onto an unheated printer bed with a lower risk of warping. Still, that comes with its own set of issues, which I soon discovered.

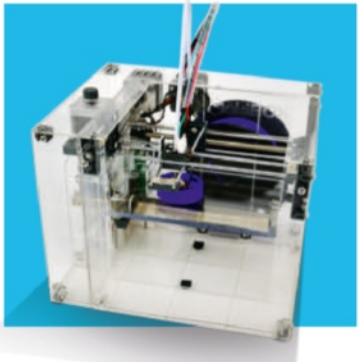


SHOPPING FOR A PRINTER?

If you have the time and relish a challenge, save money by building your own printer from a kit or open-source plans.

HOBBYIST

The MakiBox A6 LT ($200, PLA only; below) and A6 HT ($300, PLA and ABS) offer a large build volume and good performance for their price. The Printrbot Simple ($300 for kit; $400 assembled) prints up to 4 cubic inches in PLA.



MAKER

The Deezmaker Bukito Portable Mini Printer ($800 for kit; below) has a 5 x 6 x 5–inch build volume and offers all the ruggedness and versatility of the larger Bukobot series. It's an excellent entry-level machine for the serious maker.



ENTREPRENEUR

The MakerBot Replicator 2 ($2200 assembled) helped start a 3D-printing revolution, but keep an eye on the Kickstarter-funded Robox ($1400 assembled; below). Its printhead can be swapped out for a stylus cutter, a milling head, or a 3D scanner.



Maiden Voyage

I started with the simplest of projects: a two-piece rocket comprising a nose cone and a set of tail fins that press-fitted onto a standard 3-inch ½A-size model rocket engine (a thick cardboard tube filled with propellant). It needed



At the going rate of about $50 for a 2.2-pound reel of plastic filament, each of the 3D PeeWee rockets I made cost about $0.35. The two larger rockets used around $1 worth of material apiece.

a name, so I called it the 3D PeeWee. I opened the file in MakerBot's free MakerWare software, which combines the required staging and slicer applications. Much like an inkjet-printer wizard, the staging application lets you visualize the parts and adjust their size, location, and orientation on the printer bed. However, I did all the serious tweaking in the slicer, which analyzes the digitally rendered object as thousands of thin layers and then converts everything into a numerical-control (NC) programming language to give the printer specific directions. Most designs require some fine-tuning of the default settings to produce decent results. I adjusted the print resolution, the thickness of the rocket's walls, and the infill ratio, which defines the density of the walls.

It took only a half-hour to print the parts, and required about a foot of filament. That allowed me to do lots of experimenting—which was just as well, because there were false starts. Most notably, the tail fin failed to attach to the printer bed, causing it to shift ever so slightly while it was forming. That's bad news when you're relying on the printhead to operate at a tolerance of 100 microns. Suddenly, the tidy-looking rocket image on my computer screen was manifesting itself as piles of plastic angel hair.

Objects made from PLA are especially prone to detaching from the bed—more so if they make contact at only a few small points. This is less of an issue with ABS, since it already requires a heated bed to ensure that the thicker plastic adheres better. The fix was easy enough. I returned to the slicer function and added to the print instructions small disks of coarsely printed material, known as rafts. These increased the surface area of the contact points just enough to provide a firm bond. I removed them afterward with an X-Acto knife.

Not Quite Plug-and-Play

A few successful prints of the 3D PeeWee convinced me I was ready to attempt a larger, more complicated rocket with forward-swept fins. The four-part vehicle's motor section had threaded ends that connected it to the payload section and helped hold the rocket motor in place. The nose cone's printed spring fingers inserted into the payload cylinder, where they would hold it during launch and then allow it to blow loose to deploy the recovery parachute.

I had trouble printing the payload part, though. It sagged, leaving its cross section a squished oval shape rather than a perfect circle. Its threads were also poorly defined. Both issues made mating it to the engine section impossible. I went into the slicer and instructed it to add removable support webs that kept the parts from sagging. As for the threads, it took a bit of trial and error (read: numerous prints) to find the right print resolution to render them accurately.

The third rocket I'm working on has an all-in-one design that includes a three-piece fuselage, a tail section, and a nose cone in a single print. In theory, you snap away each part as you assemble it. In practice, though, I have little more to show than a few botched prints that look like abstract sculptures. I'm still experimenting with the settings so I can produce parts that are light enough to launch using a midpower engine while keeping their surfaces intact. I'm also considering switching to an open-source printer, which should give me more control over the print variables. The MakerBot I borrowed, much like other consumer units that use a proprietary architecture or operating software, provides a user-friendly experience by sacrificing some of the flexibility offered by open-source machines. The MakerWare software stages, preprocesses, and slices the object files. That removes the guesswork but also limits the ability to adjust variables such as printhead temperature and speed. This can make it difficult to print objects with thin walls or fine details.

Stand By for Launch

I launched the 3D PeeWee on a sunny Saturday in December. The bright winter sky wasn't ideal for watching a 6-inch rocket hurtle into the lower troposphere, but I was at least able to verify the craft's flight characteristics. The angled tail fins caused the rocket to spin, which stabilized its flight while also providing enough drag to limit it to around 500 feet. Then it disappeared, though I found the tail fins about a quarter-mile away. I haven't launched the larger, swept-fin rocket yet. I guess I'm bracing myself for disappointment; if I don't have a winner, I'll have to head back to Tigerlabs to lighten the rocket further and adjust its balance point by tweaking its wall thickness and infill ratio. But that's okay. The gaunt skeletons of failed rockets serve as a reminder that mastering 3D printing requires patience, a willingness to tinker, and a generous supply of plastic filament. **PopMech**



BY
JOE PAPPALARDO

PHOTOGRAPHS BY JASON MADARA





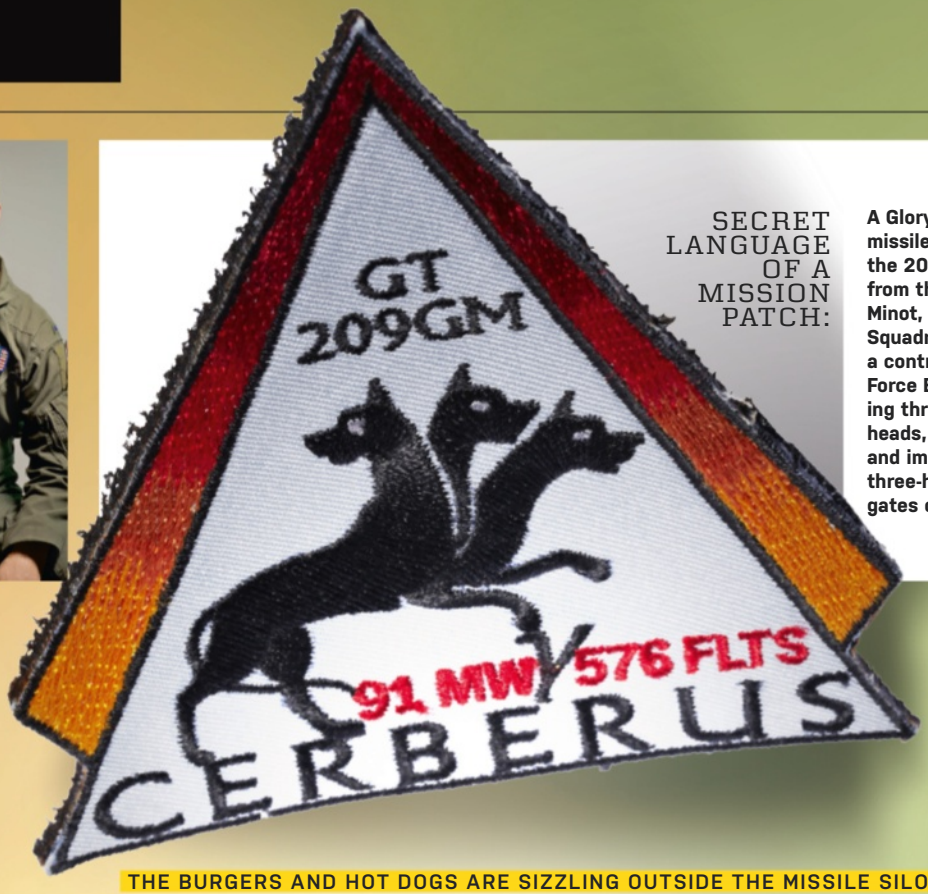
THE ARMAGEDDON CLUB

THE ERA OF THE NUKE IS NOT OVER. AMERICA KEEPS HUNDREDS OF NUCLEAR-TIPPED MISSILES ON CONSTANT ALERT, PROMISING IMMEDIATE RETALIATION IF ANYONE ELSE USES THEM FIRST. BUT TO BE A DETERRENT, MISSILES FIELDED IN THE 1970S MUST BE TRUSTED TO DELIVER. THE ONLY WAY TO PROVE IT: FIRE ONE ACROSS THE GLOBE.



Airmen who launch nuclear missiles are called key turners. From left: 2nd Lt. Evan Fay, 1st Lt. Lucas Rider, 1st Lt. Nathan Larson.

SECRET LANGUAGE OF A MISSION PATCH:

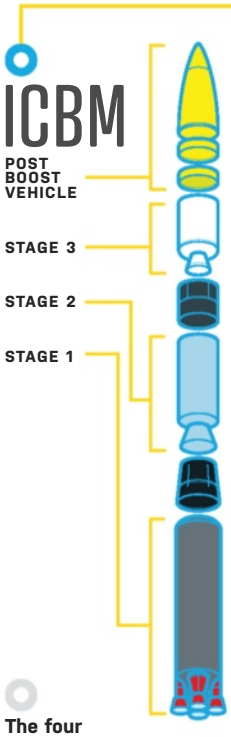


A Glory Trip (GT) is a ground-based missile (GM) test launch; this is the 209th. GT-209's missile came from the 91st Missile Wing (MW) in Minot, N.D. The 576th Flight Test Squadron (FLTS) runs the show from a control room at Vandenberg Air Force Base. This mission, launching three demilitarized nuclear warheads, takes its name, Cerberus, and imagery from the mythological three-headed hound that guards the gates of hell.

THE BURGERS AND HOT DOGS ARE SIZZLING OUTSIDE THE MISSILE SILO. A dozen airmen in green one-piece flightsuits gather around a portable barbecue, slathering ketchup and mustard on buns and relaxing in the balmy weather as they wait for the meat to cook.

Behind the airmen is an idyllic, almost stereotypical California backdrop—swells of sage-covered hills, an occasional palm tree, and a stretch of beach, white with foam from the Pacific surf. Gulls wheel overhead, and endangered snowy plovers nest in the sand. But signs on the beach belie the tranquil scenery: FATAL SHARK ATTACKS: SWIM/SURF AT YOUR OWN RISK, and MONITORED BY ELECTRONIC SURVEILLANCE.

Personnel here at Vandenberg Air Force Base, 71 miles north of Santa Barbara, Calif., call these airmen the key turners from up north. Sincere and amiable 20-somethings, they usually spend their workdays in launch capsules



The four 5.5-foot-wide nozzles of the first stage of the Minuteman III channel 210,000 pounds of thrust.

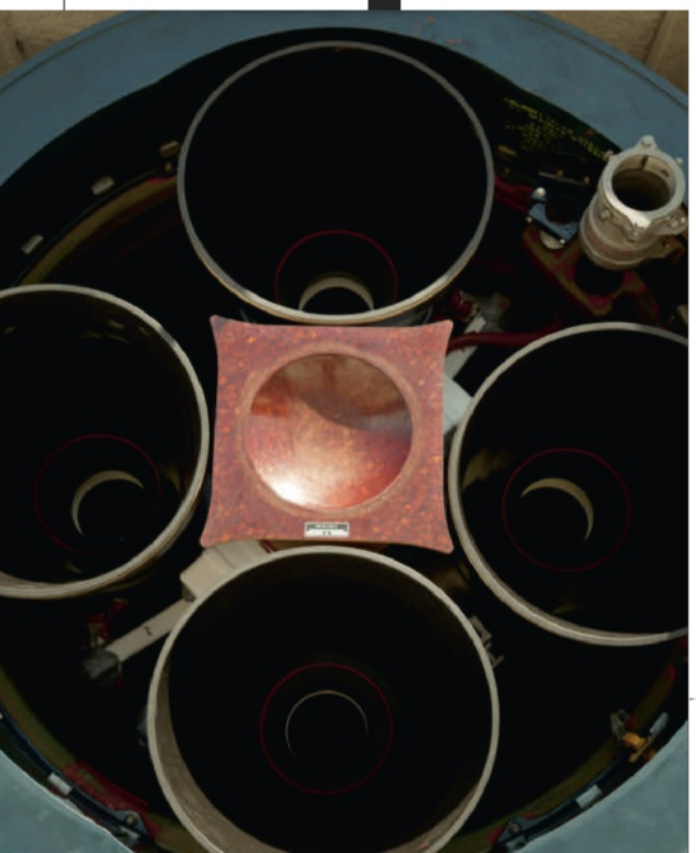
65 feet underground. They have come here to California from remote air bases in Montana and North Dakota to launch a **MINUTEMAN III INTERCONTINENTAL BALLISTIC MISSILE (ICBM).** The United States uses the Minuteman III for one thing—to drop nuclear warheads anywhere in the world in half an hour.

About 200 yards away from the relaxed cookout, Air Force maintenance officers and civilian contractors are loading the 60-foot-tall missile into a silo named Launch Facility-10 (LF-10). The civilian range-safety operations crews at Vandenberg are wary—the missile packs enough explosives and rocket fuel to kill everyone present. So they shoo the missileers away from LF-10 while the crews lower the ICBM from inside a tractor-trailer into the silo. It's a process key turners don't normally see.

One of the airmen outside the fence, 1st Lt. Lucas Rider, then of the 90th Operations Support Squadron—an Eagle Scout and a former intern on *Oprah's Search for the Next TV Star*—has been in the Air Force for three years. Like most of his peers, he had never even heard of ICBMs until his USAF recruiter told him where he was being sent for officer training. "I said, missile ops? What in the world is that?" he recalls. "I literally knew nothing about this career field." Now Rider controls the most powerful weapons ever created.

In less than 30 days he'll get the best reward the Air Force can bestow on a young missileer: He'll shoot a missile payload into space. "Knowing that I'm going to key-turn on it in less than a month is indescribable," he says, eyeing the silo. Three times a year the Air Force plucks missiles from the ICBM fields, chooses crews to launch them, and sends them to California for a test flight. (Armed nuclear warheads are tested only in supercomputer simulations.) The test flights are called Glory Trips, and this is the 209th such test flight since 1970, so it's called GT-209.

Some call a Glory Trip the Super Bowl of a missileer's career. It's the opportunity of a lifetime, and one that's hard-earned. These young airmen incessantly train to perform a task, having no real expectation that they'll ever do it. Being ready to launch doomsday weapons, it turns out, can be an inglorious job.



FORGOTTEN BUT NOT GONE

MORE THAN 20 YEARS AFTER THE END of the Cold War, the brute reality of mutually assured destruction persists. It lingers because, in an uncertain world, it works as a deterrent. The end of the Cold War did not eliminate the threat of nuclear weapons. In fact, the threat has expanded to new nations that wield longer-range missiles. "Rightly or wrongly," BBC writer Kevin Connolly summed up in late 2013, "the possession of nuclear weapons edges you closer to a seat at the high table of world politics."

Some players who already have seats at the table have long-standing geopolitical tensions with the United States. Russia still maintains 1800 nuclear weapons, and launch-tested four ICBMs in a single day in October 2013. Experts estimate that China's growing arsenal includes as many as 60 long-range missiles that can



PHOTOGRAPH BY J MUCKLE (PATCH); ILLUSTRATIONS BY MARTIN LAKSMAN

reach the U.S.—some can reach both coasts; that number does not count Chinese submarine-launched ICBMs that some experts think will be operational this year. North Korea has long-range missiles, and its underground detonation in February 2013 may be a sign that it's developing a small nuke suitable for a missile warhead.

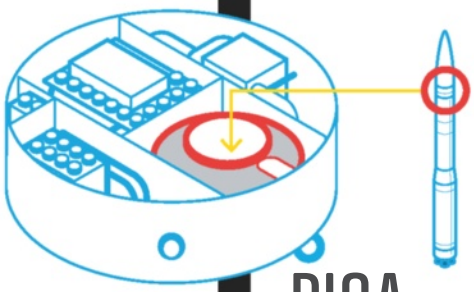
The Pentagon maintains that the promise of nuclear counterattack is the only certain way to prevent the use of nuclear weapons against America and its allies. Professionals in the ICBM world talk a lot about deterrence. Maj. Gen. Michael Carey, then commander of the 20th Air Force, which controls land-based nuclear missiles, voiced the institutional view when he visited the offices of Popular Mechanics in July 2013. "We keep a lid on World War III," Carey said.

America deploys 2130 operational warheads, according to the *Bulletin of the Atomic Scientists*. The Air Force alone keeps 450 nuclear-tipped ICBMs on constant alert at Air Force bases in remote corners of the nation: F.E. Warren AFB in Wyoming, Malmstrom AFB in Montana, and Minot AFB in North Dakota. Every 24 hours two airmen descend by elevator into a capsule, where they monitor the health of 10 nuclear-tipped Minutemen III missiles in silos up to 10 miles away from the capsule. Receiving an "emergency action message" means they initiate a launch (see "Down in the Hole," March 2011).

While other nations are fielding new launch vehicles, the U.S. is making sure that its arsenal of old but upgraded missiles still works. The Minuteman III missiles—originally scheduled for just 10 years of service—will be 70 years old when they are replaced in 2030. They need real-world testing.

That's where the Glory Trips come in. The missiles, fired from Vandenberg, drop warheads 4800 miles away into the Pacific off a tiny atoll called Kwajalein. Instead of nukes, the warheads (reentry vehicles) carry telemetry packages.

During GT-209, analysts from the Air Force and the Department of Energy will review the missile's guidance, especially the **PENDULOUS INTEGRATING GYROSCOPIC ACCELEROMETERS.** Evaluators pay particular attention to the engines, which were replaced during a $7 billion overhaul that concluded in



PIGA

These devices, stored in circular containers, use the motion of a suspended mass to measure speed across multiple axes. For guidance data, a pendulum is housed in a gyro mounted on a gimbal, which in turn is placed on a spinning platform.





The Air Force emplaces GT-209's ballistic missile with a transporter–erector, a specially designed semi with a trailer that rises to 90 degrees. The missile is lowered into its silo; warheads travel separately.



GT-209's missile rises from a silo at Vandenberg Air Force Base at 3:01 PST. After a minute of flight the missile will reach an altitude of 100,000 feet, appearing from below as a pinprick of light in the sky.

2010. Data will evaluate how they're aging. The Department of Energy monitors flights to verify the flight worthiness of the reentry vehicles. The Missile Defense Agency gathers data to learn how to thwart other nations' missiles and warheads. An Air Force "reliability scoring panel" judges the warheads' accuracy.

Glory Trips have an added benefit of boosting the morale of the best missile crews and maintainers. GT-209 is well-timed—America's ICBM professionals had a rough year in 2013. Two senior leaders, including Gen. Carey, three months after his visit to PM, were relieved of duty for personal misconduct, and some missile wings failed readiness reviews. (This year looks even worse: As this story was going to press, the Air Force announced 34 ICBM launch control officers from Malmstrom Air Force Base have been accused of cheating on monthly proficiency tests.) Two independent reports found that the morale in the missile fields is sagging. One of them, an internal Air Force study by Rand obtained by the Associated Press, found that the personnel it polled suffer from "feelings of hopelessness, tiredness, and a sense of being trapped."

The drawbacks of the career are obvious, and all the key turners can recite them: living on remote air bases; enduring a PERSONNEL RELIABILITY PROGRAM that scrutinizes personal lives; undergoing ceaseless drills and tests; and dealing with a media echo chamber that reports even small infractions—such as leaving a blast door open inside a launch capsule—as if they were national security crises. Some younger airmen, however, see an upside to the media coverage. "We are the forces they are talking about," says 1st Lt. William Swinton, a key turner with the 319th Squadron at F.E. Warren. "It's important."

The airmen at Vandenberg who are conducting GT-209 do not seem demoralized. They are enjoying a rare moment to practice the trade that consumes their lives. For all the effort they expend on tending ICBMs, key turners spend little

PRP

Airmen who work with nukes must report physical and mental strains to officials: domestic fights, cough-medicine intake, everything. A 2013 independent report says a PRP is needed but is bureaucratic and intrusive.

time in close proximity to the missiles. "I already knew that we hold ourselves to extremely high standards," Fay says. "The Glory Trip not only reinforces that, it makes me realize how much truly goes into these weapons."

LAUNCH NIGHT

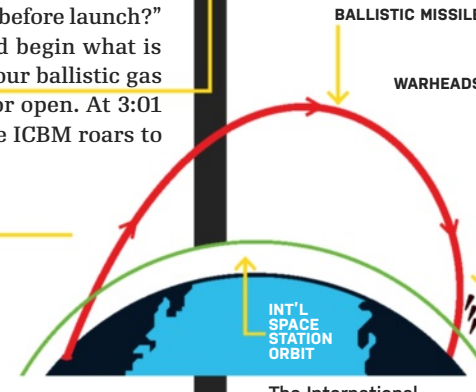
ICBM TESTS IN THE CONTINENTAL UNITED STATES TYPICALLY occur during the early morning hours. That way, they disrupt as few civilian lives as possible: Aircraft have to be diverted; marine traffic along the California coast shuts down. The State Department alerts foreign governments—especially nuke-bearing nations—to the imminent launch. It's as if a large part of the world pauses.

It's a few minutes before launch. Rider and 1st Lt. Nathan Larson insert the launch keys and fix their eyes on the digital clock, hands on the switches. Rider's body starts to feel the effects of an adrenaline surge: "Would you believe it if I said that I was nervous and kind of shaky the last few minutes before launch?"

Just after 3:00 am, Rider and Larson turn the switches and begin what is known as **TERMINAL COUNTDOWN.** Inside the silo at LF-10, four ballistic gas generators come violently to life, blowing the 110-ton silo door open. At 3:01 am, the key turners feel the launch control center rumble; the ICBM roars to life a few hundred yards away. A flickering lick of orange flame illuminates billowing smoke as the missile leaps from its hole.

Thirty seconds before a launch, the Minuteman III enters its terminal countdown. Umbilicals on the silo walls disconnect from the missile, and the weapon's onboard computer takes over the launch.

An ICBM launch has the same **FLIGHT PROFILE** as a basketball jump shot. There is an early, high-energy release, followed by an extended arc-shaped cruise that crests at an altitude of 700 miles—440 miles higher than the International Space Station's orbit—and a final plunge.



The International Space Station orbits at 260 miles above Earth; nuclear warheads reach a staggering apex of 700 miles. Still think there are no weapons in space?

After 60 seconds the Minuteman III is already at an altitude of 100,000 feet. Each of the three stages separates in 1-minute intervals. The missile's fairing falls away, powered by its own thrusters, exposing the 6-foot-long warheads. The Minuteman III launches a spacecraft, called a bus, powered by a liquid-fuel-propulsion-system rocket engine. This PSRE ("PIZZ-re") fires to aim the mock W87 warheads. The bus releases each warhead individually; the PSRE fires slightly to adjust the trajectory of each one. This all happens about 180 seconds into the flight, 200 miles from LF-10. The warheads travel the remaining 4600 miles without any power.

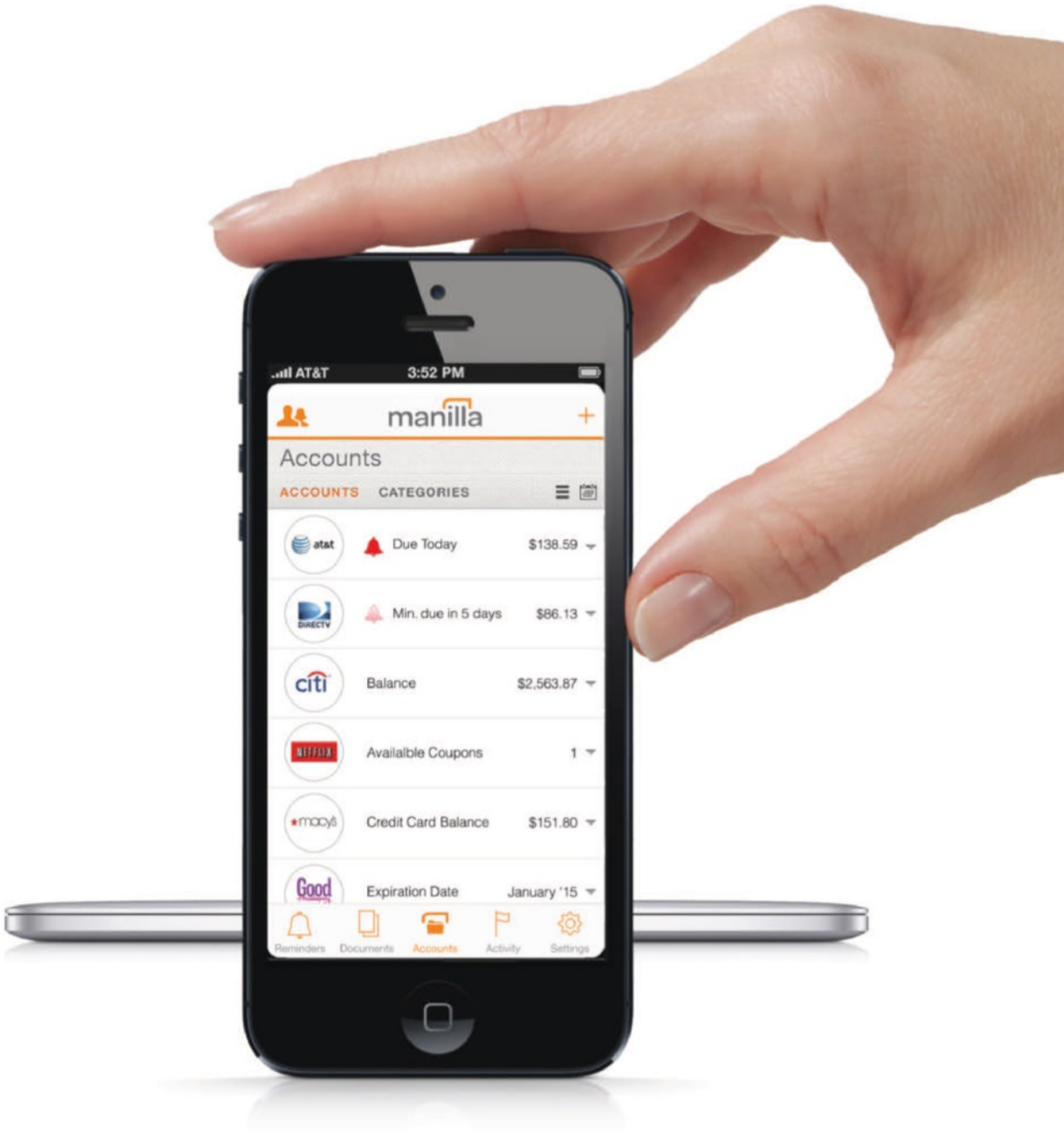
About 30 minutes later—the exact time is classified—bright pinpricks appear over Kwajalein, 2400 miles southwest of Honolulu. Each warhead is trailing a glowing shroud of superheated ionized air. Radar domes and dishes on the 5.6-square-mile Pacific atoll **SKIN TRACK** the warheads' progress. When the warheads get close, batteries of high-definition cameras capture their flights for analysis. Ten antennas on Kwajalein gather telemetry data.

Skin tracking is what professionals call the direct surveillance of an object by radar.

The three dummy warheads, shooting stars trailing in one after another, splash down on target. The reentry vehicles settle to the bottom of the ocean, too deep for recovery.

The next day Rider, Fay, Larson, and the rest of the GT-209 crew reluctantly take off the velcro GT-209 mission patches from the left arms of their uniforms. They will be able to enjoy a few more days in California before heading north, where a cold fall is already descending.

Those in the ICBM business will continue to obsess over the missiles so the rest of us can forget they exist, happily oblivious that Armageddon is still—and probably always will be—only a half-hour away. **PopMech**



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A minute ago this smartphone was all cracked up. p. 88

AUTO
Use auto apps for a connected commute, and save time, money, and aggravation. **p. 96**

HOME
As the future of incandescent lightbulbs dims, we explore home lighting's bright future. **p. 100**

GADGET SURGERY

THREE SIMPLE REPAIRS TO REVIVE YOUR BROKEN ELECTRONICS.

BY ALEXANDRA CHANG

diy Tech

MOBILE-PAYMENT APPS
4K TVS
OLD SETTINGS IN NEW LAPTOPS

The author, Alexandra Chang, solders exposed wires to the probes on a new headphone jack plug.

PHOTOGRAPHS BY **ADAM GOLFER**

THE ONE THING ALL GADGETS WILL DO IS BREAK. If your device is under warranty, that's great. But as soon as it's not covered, the bills can add up. Learning to fix your own gadgets can help extend their lifetimes so you don't end up tossing them into the back of a closet or, worse yet, a landfill. The three repairs detailed here require only basic tools and skills—any beginner can tackle them. Opening up your own gadgets can be intimidating at first, but the process can be more rewarding (and affordable) than taking the damaged device to a shop or buying a replacement.

1 Broken Headphone Jack Plug

DIFFICULTY: ●●●○○

TIME: 30 minutes to 1 hour

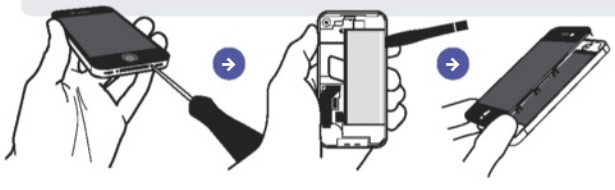
DIY FIX: $41 (including $25 for a soldering station)

OUT-OF-WARRANTY FIX: A few third-party shops will fix headphones; you'll need to search in your area. Approximately $55 to $125, plus parts.

WITH EXTREMELY THIN WIRES, headphone cables have a tendency to break. The damage often happens right next to or inside the jack plug. That's what happened to my Sennheiser HD 202 II Professional headphones. Those headphones were not particularly expensive, but many others cost upward of $300, so a DIY fix can be a bargain.

I ordered a 90-degree replacement plug from Amazon for $8—straight ones sell for less—because it had good reviews, and right-angle plugs are supposed to work especially well with phones. I cut off the offending jack plug along with about 2 inches of cable, since I had plenty to spare—the HD 202s come with a very long cable. I slid a piece of heat-shrink tubing and the plug cover onto the cable. These headphones have a side-by-side cable—a cable with two insulated wires joined together—so I carefully separated the two sides, then stripped each about 1 inch down. One side has a red wire (which is associated with the right speaker) and the other has a green wire (the left speaker); each side has a copper grounding wire. For prep I sanded the red and green layers of paint off the wires and also sanded the metal probes sticking out of the bottom of the plug.

I hooked the wires to the appropriate probes on the plug and soldered them in place. The sleeve probe on my plug didn't have a hook and was short, which made it hard to wrangle the two grounding wires. My advice: Only use the 90-degree jack plug if you're experienced at soldering. Most straight jack plugs come with longer probes, each with a hole for hooking in the wires. I melted too much solder on the sleeve probe and had to reheat and siphon the excess off that probe. Finally, I was able to fit the plug cover over the plug. But even with that delay, it didn't take long to get my headphones working.



To replace an iPhone screen, loosen the pentalobe screws and pry open the chassis. (This process is easiest with 5 and 5s models.)

2 Shattered iPhone Screen or Rear Panel

SCREEN DIFFICULTY (IPHONE 4): ●●●●○

(IPHONE 5 AND 5S): ●●●○○

TIME: 1 to 1.5 hours

REAR-PANEL DIFFICULTY (IPHONE 4, 5, 5S): ●○○○○

TIME: 5 to 10 minutes

DIY SCREEN FIX: $28 to $140, depending on the type of display and where you buy it

ILLUSTRATIONS BY MARTIN LAKSMAN

OUT-OF-WARRANTY SCREEN FIX:
$150 to $270 at the Apple Store, depending on the model of phone; $100 to $180 at a third-party shop

A SHATTERED SMARTPHONE screen is nearly as common a sighting as a smartphone itself: Americans have spent $5.9 billion on damaged iPhones, according to a survey conducted by U.S. device warranty provider SquareTrade. With an edge-to-edge glass display, the iPhone is especially vulnerable. But it's also one of the easiest gadgets to fix, thanks to an abundance of guides and repair kits. Armed with these tools, I took on a shattered iPhone 4 display and a cracked iPhone 4s back panel.

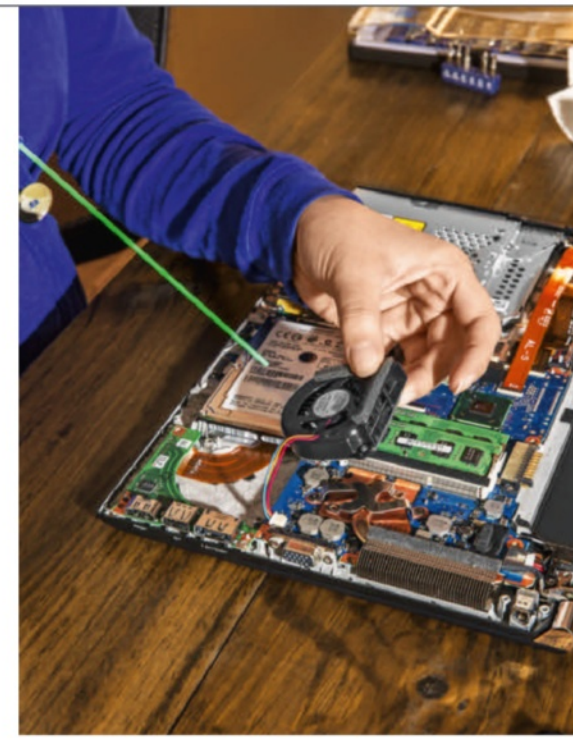
The first step: Buy parts. I ordered both the display and the back panel from Amazon, which carries an array of affordable iPhone parts from various vendors. You can get kits that come with the necessary tools, or individual parts for less. For beginners, I'd recommend buying a kit. The caveat is that most vendors through Amazon don't offer quality assurance for their parts—the low prices are matched by generally mediocre reviews.

One of the more respected vendors on Amazon is iCracked. The parts and kits are slightly more expensive than some competitors' (upward of $100), but they come with an absurdly long 99-year warranty. I also received parts and a tool kit from iFixit, a popular and thriving repair community that runs its own online store. iFixit offers a six-month warranty for all of its iPhone parts and inspects and cleans every screen. It will cost you more (an iPhone 5 kit is $140), but the money helps support the organization's work of empowering users with the necessary tools and guides to fix their own gadgets—an online resource to depend on when learning to do repairs. One important note: If you're replacing the display or back panel of an iPhone 4, you'll need to make sure to order the correct one for your GSM (AT&T and T-Mobile) or CDMA (Verizon and Sprint) model.

If you have a shattered back panel, there's no reason not to fix it yourself. It took me less than 5 minutes, and the part on Amazon costs only $5 (one that comes with a warranty is around $15). You'll need the correct screwdriver for Apple's tiny, proprietary pentalobe screws, which have the shape of a five-leaf flower.

Tackling the display is more challenging and time-consuming, especially for the iPhone 4 or 4s, because you have to take apart the entire phone to disconnect the display. (Apple made it much easier on iPhone 5 models.) I consulted iFixit's excellent step-by-step guide for this repair. One challenge is the size of the iPhone parts—the screws are ridiculously small and difficult to handle. You'll definitely need a magnetic screwdriver. Keeping track of all the tiny pieces is another hurdle. IFixit sells a magnetic project mat for $15, but I found that for this repair, a couple of strips of tape with the ends folded under to stick to the table worked equally well. Just make sure to set aside the screws in the order you take them out so that you can easily reassemble everything correctly.

It's important not to pull too hard on any of the cables, including the digitizer and display-data cables on the new screen, which attach to the logic board. They will rip! (Don't ask how I know this.) But be patient and you'll get the new iPhone 4 display back onto the body, leaving you with what appears to be a brand-new phone.



To fix a busted fan inside an old laptop like the Toshiba Portégé R835 pictured here, first try looking for an online manual to teach you how to open up the computer. Then carefully remove the fan, clean out the surrounding area, and install a replacement part. Ensure the computer's cables are properly connected before sealing the machine back up.

Popular Mechanics

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3

Busted Laptop Fan

DIFFICULTY: ●●●○○

TIME: 20 to 40 minutes

DIY FIX: $30 to $50 (depending on the cost of the fan)

OUT-OF-WARRANTY FIX: $60 to $100 per hour (part not included)

LAPTOP FANS COLLECT DUST and overheat with use. The result is a fan that whirs loudly or one that won't work at all. I dealt with a broken fan inside an old Lenovo ThinkPad T400. When I tried to turn the laptop on, a message—fan error—popped up during startup, then the computer immediately shut down.

I turned to the manufacturer for advice, as Lenovo posts guides for its machines online. Following the directions, I removed the keyboard, trackpad, keyboard bezel, and speakers. For this repair, a magnetic mat came in handy for organizing the many screws that popped off. The guide also listed fan models that T400s are compatible with. I purchased one on eBay for $30 from a vendor with a 98 percent approval rating. The package arrived promptly and even came with thermal paste.

Opening up the laptop revealed a dusty mess. I wiped the larger surfaces with a lint-free cloth, then used compressed air to clean out the area surrounding the fan. The most challenging part was putting everything back in place, with the cables routed correctly. The manual included illustrations, which helped—and the parts were much easier to handle than, say, an iPhone's. In the end, what I thought would be my most difficult repair turned out to be a snap.

Digital Clinic

BY RACHEL Z. ARNDT

Q+A

Peer-to-Peer Payments

What are my options for using my phone to send money to a friend?



There's been a boom in mobile payment apps recently, so you have a few options. The leaders in the game are Venmo, which launched in the U.S. in 2012; PayPal, a pioneer in the field, cofounded by Tesla and SpaceX entrepreneur Elon Musk; and Square, the payment service started by Twitter's Jack Dorsey.

Square Cash takes the fewest steps to use and is free. The idea is to make transferring money as easy as sending an email: Compose a message to the recipient of your money, and CC cash@square.com, with the amount you want to send in the subject line. (Write whatever you like in the email body, or just leave it blank.) Almost immediately you will get a return email that contains a link to the Square website; follow that link to type in your debit card number. If it's your friend's first time using the service, he will be asked to do the same, and the money will be transferred within two business days.

ILLUSTRATION BY JACK DYLAN

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Of all the services, I recommend Venmo, which, like Square, is free if you use a debit card, and, like PayPal, is owned by eBay and allows you to pull from a balance held by the service. Best of all, Venmo promises overnight processing. The service hopes to create its own social network by giving users the option to contribute to a feed that shows transactions within their circle—not the amount but what the money is for.

To 4K or Not to 4K?

I'm tempted to buy one of the new 4K TVs, but I know there's not much 4K content. How will standard and hi-def video look on one of these sets?

Frankly, 4K-TV pictures are beautiful. Also called UltraHD, or UHD, 4K televisions have a resolution of 4096 x 2160 pixels; HD is 1920 x 1080 pixels. As you point out, though, barely anyone shoots movies or TV shows at 4K resolution. What you'll be watching on your 4K set, therefore, will probably be standard-def or HD video that's been scaled up to fill in all those extra pixels. To do that, the TV stretches the data in each pixel, using algorithms to fill in the missing image information. TV manufacturers say that results in a more detailed image. However, if the algorithm's no good—if it just quadruples the size of each pixel, for instance—content will look worse on a 4K TV.

Processors such as Sony's 4K X-Reality Pro and Samsung's Quad-Detail Enhancement can make HD content look great when scaled up, but it's harder for them to deal with standard-definition content, because there's simply less data to work with. "The upscaling is as good as the source material," says Rob Manfredo of Sony, whose 4K TVs eliminate visual noise and fill in details using an image database. The process works wonderfully with 1080p Blu-ray and 1080i satellite video, he says, but not as well with lower-resolution material, such as 480p and 720p.

Preferences

I just got a new laptop. I know I can move all my data over. Can I duplicate preferences too?

It's fairly easy to duplicate your preferences as long as you're staying in the same OS universe. Macs won't understand PC preferences and vice versa. If your old computer still works, you can transfer everything directly to the new one. (Note: You'll be computerless during the process.)

For PCs, you'll need to buy a cord, called the Easy Transfer Cable for Windows, to link the two machines and then run a program paired with the cable. (The cord will cost you between $5 and $20.) On a Mac, in the same window where you would choose to migrate from a Time Machine backup, choose From Another Mac, connect the two computers via Ethernet, and follow the instructions on the screen. Your preferences, along with everything else, will then be moved to your new machine.



Another option is to restore your data and preferences from an external-drive backup. If you practice good digital hygiene, you probably already back up your laptop; this guarantees your data will be safe in case your machine breaks. If not, you'll need to set this up. To make a complete backup from a PC on an external drive, first format the drive as NTFS. Then go to the Backup and Restore Center in the Control Panel and choose Back Up Computer. On a Mac, once the drive is plugged in, go to Time Machine Preferences to select it as the backup location. Then choose Back Up Now in the Time Machine menu.

Depending on how much data you have and how the drive is connected (USB, Thunderbolt, and so on), the process could take many hours or even a few days. Once it's done, you're ready to move the data from the external drive to your new computer.

Assuming your new PC didn't come with an installation disc—few do these days—restart it and press F8 over and over as it's booting up. After choosing Repair Your Computer and following the prompts, select Windows Complete PC Restore and plug in your backup when instructed. On a Mac, just turn on the computer and, when prompted, choose to migrate information from the Time Machine backup or from whatever disk you've prepared. **PopMech**

? GOT A TECHNOLOGY PROBLEM? **ASK THE EDITORS ABOUT IT.**

Send your questions to **pmdigitalclinic@hearst.com** or over Twitter at @PopMechDigital or to Digital Clinic, Popular Mechanics, 300 W. 57th St., New York, NY 10019-5899. While we can't answer questions individually, problems of general interest will be discussed in the column.

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Saturday Mechanic:
HACK YOUR COMMUTE

MOBILE PHONE APPS THAT RESTORE THE FUN IN GETTING THERE.

BY MICHAEL FRANK AND MICHAEL AUSTIN

Your car's technology is usually frozen in time on the day the vehicle leaves the dealer's lot, which makes factory navigation systems difficult or impossible to upgrade. Load the right apps on your mobile device, however, and you'll soon be avoiding traffic, locating speed traps, and finding the nearest cup of coffee with greater speed and accuracy than your in-car system can provide.

INRIX, the world's largest traffic-data company, gets most of its information from sensors installed on commercial vehicles—long-haul semis, taxis, even cable-company service trucks. Factor in the intel generated by INRIX's mobile app and the recent addition of private vehicles that automatically (and anonymously) stream data to the cloud and it all adds up to petabytes of road information every day.

Apps such as Waze that don't have nearly as many data sources as INRIX can be effective too. Mobile apps from Garmin and Telenav (which makes Scout) take advantage of your phone's data connection for more frequent updates and features such as integrated text messaging. Of course, the potential of phone apps depends heavily on a reliable signal, so in rural areas most in-car systems are more dependable. But when you are connected, there's no better way to get up-to-the-second traffic updates that speed you on your way.



The Generalists

WANT TO SHAVE PRECIOUS MINUTES OFF YOUR DRIVING TIME? THESE FOUR APPS ALL PROVIDE INSTANTANEOUS TRAFFIC UPDATES TO GIVE YOU THE PERFECT ROUTE. EACH ALSO HAS ITS OWN SUITE OF SPECIAL FEATURES.

GARMIN STREETPILOT

iOS ($40), Windows ($30)

This pricey software bests the freebies in our roundup with photo-realistic mapping and right-now prompts, which worked well even when we were cruising through rural Utah without a cell signal. That detail and immediacy are the result of maps that live locally on your smartphone, not in the cloud. Another distinguishing feature is Garmin's deep mass-transit database. The app can direct you to the nearest parking garage, drop a virtual pin on the map to help you remember your car's location, and then guide you to the next bus on the corner (yes, it knows the schedule), or subway, or ferry. Live traffic is supplied by Here (formerly, NavTeq) and augmented by crowdsourced data.

WAZE

iOS, Android, BlackBerry (all free)

Yes, Google owns the scrappy Waze, and, no, it's not Google Maps with added directions. The maps and routings are built by 50 million worldwide users. Traffic data in the U.S. is based entirely on the progress (or lack thereof) of "wazers" on the road. These volunteers provide information on speed traps, accidents, and other road events, which fellow wazers confirm and update. But Waze needs a connection; lose service and most of the info is unavailable. The police and traffic warnings are highly reliable, and points-of-interest searches are augmented by larger databases such as Google, Yelp, and Foursquare.

SCOUT

iOS, Android, Windows (all free)

This product comes from mapping- and traffic-service provider Telenav, the backbone of several carmakers' nav systems. We like the layers of information that come with directions, such as weather forecasts. Two other features stand out: OnMyWay texts contacts that you're en route, and the Meet Up function lets multiple users see the others' progress in real time. Scout also acts as an event guide, with listings of movie times, concerts, and so on. In-app upgrades include speed traps and speed cameras. Like Waze, Scout's prompts may be a beat slower than those of Garmin's StreetPilot, but, hey—it's free! We also love that you can choose a monster truck as the icon for your car.

INRIX TRAFFIC

iOS, Android, Windows, BlackBerry (all free)

What makes this app special is that it not only tells you the current state of traffic, it also predicts what traffic will be like in 15 minutes or even a few hours. It also figures out detailed traffic information on surface streets and on-ramps. The app gives the optimum departure time so you encounter the minimum traffic delays, and offers shockingly accurate travel times, which you can text to your friends. The downside: INRIX Traffic only provides the best route, not turn-by-turn instructions. The free version lets you save two locations (say, home and work) for quick traffic lookups. A $25 upgrade adds access to traffic cameras and unlimited saved locations.

The Specialists

DIRECTIONS AND TRAFFIC ALERTS AREN'T THE ONLY WAYS TO IMPROVE YOUR COMMUTE. THESE THREE APPS HELP YOU STEER CLEAR OF COPS, DRIVE GREEN, AND FIND A CHARGE.

TRAPSTER

iOS, Android, Windows, BlackBerry (all free)

For those averse to tickets and fines, Trapster uses voice prompts to flag red-light and speed cameras along with known speed traps. Data is crowdsourced from 20 million users, and accuracy is solid.

GREENMETER

iOS ($6)

Gentle driving helps boost mpg, which is good for your wallet and your planet. So if you're hitting the gas or the brakes too hard, greenMeter reads your phone's accelerometer and lets you know. To generate more accurate fuel-use metrics, the seriously geeky can program in additional parameters such as car weight, coefficient of drag, and horsepower.

PLUGSHARE

iOS, Android (both free)

It helps EV and plug-in-hybrid drivers find juice at malls, coffee shops, and parking lots. You can reserve a charger and, if necessary, pay for the fill-up. Other useful data: identifying fast or slow chargers, and a metered clock that counts down the charge time.



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Car Clinic

BY BEN WOJDYLA

Q+A

The Battery Spa

Is it possible to rejuvenate a car battery by adding more acid to it? I've heard that some dead batteries can be restored.



You might be thinking of older batteries, which need to be periodically checked and topped off with water. Most new batteries are maintenance-free, so you can't mess with the components inside. Older battery designs lose water in the electrolyte—a mixture of about one part sulfuric acid and two parts water—from evaporation. If you have this kind, check it twice a year and add distilled water only as needed. Adding acid actually makes a battery deteriorate faster.

It comes down to how batteries work and eventually lose their ability to hold a charge. In a typical wet-cell design, a lead plate (negative) and a lead oxide plate (positive) are immersed in the electrolyte. A porous separator keeps the plates from touching and shorting out. Each pair of plates generates a certain amount of voltage, and multiple sets are combined for higher output. Drawing voltage from a battery causes the plates to react with the electrolyte, which forms lead sulfate; this chemical process creates water and releases

ILLUSTRATION BY JACK DYLAN

IN THE TOOLBOX

Battery-terminal cleaner What might seem like a bad battery could just be an underperforming one with corrosion on the terminals. That gunk could easily be removed by using this tool, which is really just a two-in-one brush. Disconnect the wires to the battery and use the cleaner's internal wire brush to scrub the crust off the battery posts. Pop off the cleaner's top and the round brush cleans the insides of the terminal connectors.



electrons that generate current. Eventually the water dilutes the electrolyte, which can't keep reacting, and that results in a discharged battery. Charging the battery reverses the chemical reaction and restores the plates' chemistry.

The process deteriorates over time. The plates gradually build up oxidized debris that reduces their ability to react. This buildup is called sulfation. If you increase the acidity of the electrolyte, it accelerates sulfation.

Batteries generally have a life span of five years, and advanced designs can last seven to 10 years, so don't feel too bad if your old battery makes its way to the recycler. You can extend the life of your battery by making sure it stays fully charged and avoiding rapid charging.



TOOL OF THE MONTH

BLACK & DECKER SMART BATTERY CHARGER $80 TO $150

The microprocessor that controls the Smart Charger, which comes in 15-, 25-, and 40-amp versions, feeds a constant voltage to accelerate charging until the battery is nearly topped off, and then gradually reduces the current in the final stages, which helps extend battery life. The Smart Charger also has a reconditioning feature that pulses electricity to break up and dissolve sulfation deposits on the positive and negative plates. One knock on the product: It considers any battery with a charge of less than 2 volts to be dead and beyond revival, so it won't feed electricity to it. That's not the case with most regular chargers, which can revive a battery with zero juice.

WHY WE LIKE IT

It works up to three times faster than traditional chargers, and it's foolproof: If you accidentally hook up positive to negative, the charger won't run. Plus, the reconditioning feature can add years to the lifetime of your battery.

Oil Drainage

When the oil-pressure light came on in my 2013 Dodge Dart, I started to pull over, and then the engine stopped. I got out of the car and saw a line of oil behind me on the road and all around the right side of the car. The salesman said the car shuts itself off before any damage happens. Is that true?

Most of the time that light means bad news—an oil-pressure problem is one of those things that happens suddenly rather than slowly getting worse over time. The trail of petroleum from your car could be the result of the oil filter, which is on the same side of your car as the oil spatters. The Dart turbo has a replaceable filter covered by a reusable cap—and I'm guessing that cap wasn't properly tightened at your last oil change. The fail-safe engine shutdown probably prevented damage, but any time an engine runs that low on oil there's always a chance the internal parts took some serious wear that you can't inspect without an expensive teardown. Once your car is repaired, watch for oil consumption or leaks that could signify a larger problem. **PopMech**

? GOT A CAR PROBLEM? ASK BEN ABOUT IT.

Send your questions to **pmautoclinic@hearst.com** or over Twitter at @PopMechAuto or to Car Clinic, Popular Mechanics, 300 W. 57th St., New York, NY 10019-5899. While we can't answer questions individually, problems of general interest will be discussed in the column.

PHOTOGRAPH BY **BEN GOLDSTEIN**

diy Home

INSTALLING USB OUTLETS
SHAPING TILE
WEEP HOLES
RIGHT-ANGLE DRILLS

UNDERSTANDING LED LIGHTBULBS

FEELING LOST IN THE LIGHTBULB AISLE? WE'RE HERE TO HELP. *BY DAVID AGRELL*



INCANDESCENT ERA, RIP. Like it or not, it's time to move on. Traditional incandescent lightbulbs are gone—not banned, precisely, but phased out because the Energy Independence and Security Act (EISA), passed in 2007, requires them to be about 25 percent more efficient. That's impossible to achieve without decreasing their luminous flux (brightness), so, instead, manufacturers have shifted to more energy-efficient technologies, such as compact fluorescents (CFLs), halogens, and LEDs.

Of course, not everyone is embracing these next-gen lightbulbs. Some wonder why we need a mandate to use them, if they're so great. The fact is, after more than a century of incandescents, we've become attached to them. They're cheap, they dim predictably, and they emit a warm and familiar glow. Weaning ourselves off them won't be easy: Just as the 40- and 60-watt phaseout went into effect on Jan. 1, about half of the 3.2 billion screw-base bulb sockets nationwide still housed incandescent bulbs.

So, what now? According to a survey by switch manufacturer Lutron, two-thirds of American adults are aware of the phaseout, but only one in 10 are "very knowledgeable" about replacement options. Most of us will probably buy halogens without even noticing. At about a dollar apiece they are cheap, and they look, feel, and function almost exactly like tradi-

tional incandescents. But they're only about 25 percent more efficient—just enough to meet EISA standards. Meanwhile, CFLs, which are inherently flawed and generally unpopular, are steadily losing market share.

That leaves LEDs, which offer the most sustainable—and exciting—alternative to incandescents. For starters, they're highly efficient: The average efficacy of an LED bulb is 78 lm/w (lumens per watt), compared with around 13 lm/w for an incandescent and approximately 18 lm/w for a halogen equivalent. Yes, LEDs have their shortcomings: Buying an LED bulb doesn't seem as intuitive as picking up an incandescent from your local drugstore, and the up-front cost is high. But once you get to know the technology and the incomparable versatility that LEDs offer, you'll see the demise of the incandescent as an opportunity. Here's a primer that addresses your concerns and helps you navigate the dazzling array of choices.

AREN'T LEDS EXPENSIVE?

The days of the $30 LED bulb are over. As demand has increased and manufacturing processes have become more streamlined, costs have plummeted. Additionally, utility company rebates have driven the price of many household replacements to below $10; in some regions they cost half that. Sure, that's a long way from the 50-cent incandescent, but consider this: LED bulbs consume one-sixth the energy of incandescents and last up to 25 times longer. Replacing a 60-watt incandescent with an LED equivalent will save you $130 in energy costs over the new bulb's lifetime. The average American household could slash $150 from its annual energy bill by replacing all incandescents with LED bulbs.

WHAT AM I LOOKING AT HERE?

Today all lightbulb packaging carries the Federal Trade Commission's Lighting Facts label, which lets you compare similar bulbs without relying on watts as the sole indicator of performance. It gives information about the bulb's brightness (in lumens); yearly cost (based on 3 hours of daily use); life expectancy (in years); light appearance, or color temperature, measured in Kelvins (K); and energy consumed (in watts). Remember: An LED bulb's wattage rating doesn't indicate its brightness; its lumens rating does. A 60-watt-equivalent LED bulb delivers about 800 lumens, roughly the same as a 60-watt incandescent.

You may see a different label produced by the Department of Energy. Confusingly, it's also called Lighting Facts, though it's geared more toward retailers than consumers. The DOE label doesn't give the bulb's estimated yearly cost or life expectancy, but it does provide information on the bulb's color accuracy (more on this later).

I MISS MY BULB'S WARM GLOW

The higher the bulb's color temperature, the cooler its light. A candle glows at a color temperature of 1500 K. That CFL you tried but hated because its light was too harsh was probably running at around 4500 K. LED bulbs marketed as incandescent replacements usually have a color temperature of 2700 K, which is equivalent to typical warm white incandescents.

But that's only part of the story. The quality of a bulb's light also depends on its color accuracy, also known as the color rendering index (CRI). The higher the bulb's CRI, the more realistically it reveals colors. Incandescent lightbulbs have a CRI of 100, but most CFLs and LED bulbs have CRIs in the 80s. According to a recent study

SAME FAMILY, DIFFERENT CHARACTERISTICS

LIFX
Funded by a Kickstarter campaign that raised $1.3 million in six days, LIFX bulbs concoct wild colors that can be controlled via a smartphone app.



CREE TW SERIES
Thanks to a bluish, neodymium oxide coating that boosts red and green hues, these bulbs have a comparatively high CRI of 93.



GE ENERGY SMART
These bulbs look nearly identical to traditional bulbs, but their snow-cone design is best-suited for downward-lighting applications.



SYLVANIA ULTRA SE
The color of an incandescent bulb warms as its light dims. The Ultra SE emulates the effect by combining white and yellow LEDs.



PHILIPS SLIMSTYLE
The LEDs are arranged at the outer edge, helping eliminate the need for a large heat sink while also providing omnidirectional light.



PHOTOGRAPHS BY GREGG DELMAN

by the DOE, only a handful of LED bulbs have CRIs in the 90s, though that will improve as efficacy increases. Note that the CRI is not always listed on the packaging, so you may have to search the manufacturer's website for it.

THESE BULBS DIM, RIGHT?

LED bulbs sold as "dimmable" work acceptably with most newer switches. The best dim to about 5 percent, though at that level some produce a faint buzzing. Make sure you buy a bulb that has been verified to work properly with your switch; check the manufacturer's website for a list of compatible dimmers.

If you need to install a new switch, buy something specifically engineered to work with LED bulbs, such as Lutron's CL series or the Pass & Seymour Harmony Tru-Universal Dimmer by Legrand. But be warned: These switches are sometimes larger than older dimmers. In most cases that shouldn't be a problem, but if you have an overcrowded electrical box, you may need to upgrade it to accommodate the new dimmer.

WHERE CAN I USE THEM?

Most household LED bulbs follow dimension guidelines for the familiar A19-shaped bulb. Some have a bulky, space-age-looking heat sink; others incorporate this necessary part more elegantly into the engineering. So-called snow-cone designs have a heat sink that takes up the entire lower half of the bulb. These emit directional light only, which is acceptable in pendant fixtures but throws unwanted shadows when installed in, for example, a table lamp with a shade. For that you'll need an omnidirectional bulb, so check the packaging before you buy. Ready for complete adoption? You'll find LEDs in floodlights, spotlights, and recessed-lighting formats, as well as in designer formats such as the flat panels of the Pixi system.

OKAY, NOW IMPRESS ME

Wi-Fi-connected LED bulbs, such as those from Connected by TCP, can be operated from a smartphone. Taking it a step further, platforms such as Philips Hue and LIFX combine red, green, blue, and sometimes white LEDs to produce millions of colors, from bright purples to daylight whites. Most offer stand-alone, plug-and-play functionality, so you don't need to buy into a larger connected system. Integrate them into an IFTTT (if this, then that) recipe and their colors automatically adjust to suit, say, the weather, the time of day, or which sports team is winning.



How a Chicago Doctor Shook Up the Hearing Aid Industry with his Newest Invention

New nearly invisible digital hearing aid breaks price barrier in affordability

Reported by J. Page

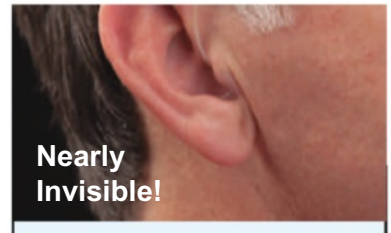
Chicago: Board-certified physician Dr. S. Cherukuri has done it once again with his newest invention of a medical grade **ALL DIGITAL affordable hearing aid.**

This new digital hearing aid is packed with all the features of $3,000 competitors at a mere fraction of the cost. **Now, most people with hearing loss are able to enjoy crystal clear, natural sound—in a crowd, on the phone, in the wind —without suffering through "whistling" and annoying background noise.**

New Digital Hearing Aid Outperforms Expensive Competitors

This sleek, lightweight, fully programmed hearing aid is the outgrowth of the digital revolution that is changing our world. While demand for "all things digital" caused most prices to plunge (consider DVD players and computers, which originally sold for thousands of dollars and today can be purchased for less then $100), yet the cost of a digital medical hearing aid remained out of reach.

Dr. Cherukuri knew that many of his patients would benefit but couldn't afford the expense of these new digital hearing aids. Generally they are *not* covered by Medicare and most private health insurance.



SAME FEATURES AS EXPENSIVE HEARING AID COMPETITORS

- ✓ **Mini Behind-The-Ear hearing aid with thin tubing for a nearly invisible profile**
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- ✓ **Feedback Cancellation eliminates whistling**
- ✓ **Wide dynamic range compression makes soft sounds audible and loud sounds comfortable**
- ✓ **Telecoil setting for use with compatible phones, and looped environments like churches**
- ✓ **3 programs and volume dial to accommodate most common types of hearing loss even in challenging listening environments**

The doctor evaluated all the high priced digital hearing aids on the market, broke them down to their base components, and then created his own affordable version—called the MDHearingAid® AIR for its virtually invisible, lightweight appearance.

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Of course, hearing is believing and we invite you to try it for yourself with our RISK-FREE 45-day home trial. If you are not completely satisfied, simply return it within that time period for a full refund of your purchase price.

Can a hearing aid delay or prevent dementia?

A study by Johns Hopkins and National Institute on Aging researchers suggests older individuals with hearing loss are significantly more likely to develop dementia over time than those who retain their hearing. They suggest that an intervention—such as a hearing aid—could delay or prevent dementia by improving hearing!

"Satisfied Buyers Agree AIR Is Best Digital Value!"

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"Almost work too well. I am a teacher and hearing much better now" —Lillian Barden, California

"I have used many expensive hearing aids, some over $5,000. The Airs have greatly improved my enjoyment of life" —Som Y., Michigan

"I would definitely recommend them to my patients with hearing loss" —Amy S., Audiologist, Munster, Indiana



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BEST DRIVER





Tool Test

RIGHT-ANGLE DRILL

A CORDLESS RIGHT-ANGLE DRILL helps you easily do work that would otherwise cause considerable frustration. For example, it can be used in confined wall and ceiling cavities to bore holes or drive screws. Sound like drudgery? Not to us; testing these eight machines was a blast. We bored into a Douglas fir 2 x 8 using a ¾-inch spade bit and drilled through ¼-inch steel. We even subjected our top contenders to a nasty bathroom-remodeling job before declaring a three-way tie among drills at three price points. Each succeeds for different but equally valid reasons. *BY ROY BERENDSOHN*

MILWAUKEE 2615-21

RANKING ★★★★★

Price: $281

Volts: 18
Amp-hours: 3

¾-inch holes: 170

Likes: Milwaukee equips its tool with a 10-position clutch for improved performance driving wood screws. But the drill is a capable hole maker in wood and in steel. We also liked the ratcheting chuck.

Dislikes: Could use a bit more trigger sensitivity. It can actually be too aggressive.

BOSCH ADS 181-101

RANKING ★★★★½

Price: $230

Volts: 18
Amp-hours: 3

¾-inch holes: 248

Likes: "This is definitely industrial-duty," tester and contributing editor Joseph Truini says of the Bosch. The only tool with a ½-inch-diameter chuck, it's heavy and long, weighing nearly 5 pounds and spanning almost 14 inches.

Dislikes: You have to grip the tool quite low to avoid blocking the motor's air vents.

DEWALT DCD 740C1

RANKING ★★★★½

Price: $195

Volts: 20
Amp-hours: 1.5

¾-inch holes: 68

Likes: DeWalt's deep-pocket chuck can swallow a 2-inch screwdriver bit, allowing just a stub to protrude, thus increasing your chances of squeezing into tight places.

Dislikes: In the unlikely event you need more hole-drilling capacity, you'll have to upgrade to a 3- or 4-Ahr battery.



MAKITA BDA350

RANKING ★★★★★★

Price: $355

Volts: 18
Amp-hours: 3

¾-inch holes: 163

Likes: A 2½-inch span from the chuck's front to the back of the head gives the Makita drill an edge in confined spaces. It's a stout borer in both wood and steel.

Dislikes: The tradeoff is that the chuck that gives it a small front-to-back dimension is not as convenient as a keyless type.

RIDGID R8223402

RANKING ★★★

Price: $150

Volts: 18
Amp-hours: 3

¾-inch holes: 27

Likes: JobMax is Ridgid's unconventional platform that allows you to place different heads on a single motor body. If you already own a JobMax motor body and other heads, you've got it made.

Dislikes: Bores comparatively few holes. Tool does not stand up on its own.

HITACHI DN 12DYK

RANKING ★★★★½

Price: $213

Volts: 12
Amp-hours: 2

¾-inch holes: 63

Likes: The only drill in the test that relies on a nickel–cadmium battery, the Hitachi is very basic. Weighing 3 pounds, 6 ounces, and measuring about a foot long, it slides into your back pocket. Yet this little guy is a respectable drill and driver.

Dislikes: A bit slippery. Needs some overmold.

RYOBI P241

RANKING ★★★★★★

Price: $200

Volts: 18
Amp-hours: 4

¾-inch holes: 257

Likes: There's no secret to Ryobi's success. If you put a 4-Ahr battery in the tool, it can punch one hole after another. But it has more to like than hole-drilling mileage. It has enough torque for respectable metal drilling, and a magnetic tray above the battery for bits. We like its comfy trigger.

Dislikes: None.

PORTER-CABLE PCC 520B

RANKING *Unrated*

Price: $64 without battery

Volts: 18
Amp-hours: 1.3

¾-inch holes: 26

Likes: None.
Dislikes: It's rare that a tool flunks our tests. But we can't rate this one. We tried two and smoked the motor in both. The first made 15 holes, then acrid smoke poured forth. The next tool produced 26 holes before it smelled like burning plastic. None of the other tools bored a hole with even a whiff.

PHOTOGRAPH BY **GREGG DELMAN**



Home Clinic

BY ROY BERENDSOHN AND DAVID AGRELL

Q+A

Docking at the Wall

I have a whole bunch of devices that are charged via USB, so I'm thinking about installing an electrical outlet with built-in charging ports. It's a pretty straightforward project, right?

These receptacles are great—they eliminate the need for bulky USB adapters that hog valuable outlet space. They are especially useful by the bed, where many of us stash all kinds of USB-equipped devices, such as phones, tablets, and e-readers. That stuff competes for space on a standard duplex outlet that may already be serving a desk lamp or a clock.

But to answer your question: Yes, USB receptacles are fairly easy to install, but there are a few things you should know before you switch off the breaker and remove your old outlet.

First, these receptacles are generally available in two basic configurations: One is a combined 120-volt and DC-charging device (like the one pictured here); the other is for USB charging only. The latter may be fine next to a regular outlet in a home office, but it's not much use on its own by the bed. Next, keep in mind that though both types of outlets have multiple USB ports, most have a total charging capacity of 5 amps or less. The more demanding the charge load you place on them, the more slowly your electronics will charge. In fact, many USB outlets can't charge two tablets at the same time. If a couple of smartphones, an iPad, and a Kindle all need an overnight charge from one outlet, check its USB amp output before buying it.

Finally, these outlets are deeper than a standard receptacle. While a typical receptacle measures about 1⅛ inches deep, these devices vary from 1⅜ inches to 1⅞ inches. Big deal? Not really, unless you're working in an old house with small electrical boxes or you have a box that's already crowded with wires. Don't jam the USB outlet into the box and hope for the best. Either choose another location or do the necessary electrical renovation

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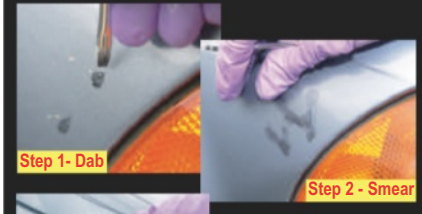
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and install a larger box.

Otherwise, wire these devices as you would any standard receptacle. Make a neat, electrically sound connection at the terminal screws for the hot (the ungrounded conductor), the neutral (the grounded conductor), and the ground (the equipment ground). Wrap the exposed wire clockwise around the screw, and tighten the screw firmly. Some devices give you the option of a small brass clamp under the screw head. Just take the stripped end of the wire, place it under the clamp, and tighten the screw on top of the clamp. Other USB outlets are available with prewired pigtails. These simply attach to the house wiring with wire connectors.

Tile File

I installed some marble tile on a countertop. In one area where I cut the tile, the edge is a bit sharper than I'd like. Anything I can do to fix it in place?

You can shape natural stone quickly and neatly with a carbide-grit file. Most have a coarse texture on one side for quick removal and a finer side for smoothing. In fact, for this job you could probably skip the coarse side. For an extra-smooth finish, use a diamond file and then some 320-grit aluminum oxide sandpaper mounted to a block.

Bug Out

We live in a brick house, and the small holes along the bottom of the exterior walls are always filled with bugs. I'm tired of cleaning them out. Can I just seal these gaps with caulk?

That's not a good idea. These are weep holes, and they allow moisture that the bricks have absorbed to drain; they also provide a small amount of ventilation. However, as you've discovered, they often attract bugs seeking a cozy shelter. Even worse, they can become entryways for more worrisome critters such as mice and snakes.

One low-tech solution is to stuff a copper or plastic scouring pad into each hole. (Don't use steel wool, which will disintegrate in days.) That'll keep out the larger beasts while allowing moisture to exit. A better fix, though, is to install a protective barrier, such as the Bug Out Weep Hole Insect Barrier, which consists of a one-way plastic door covered in tiny pinholes to allow for ventilation. Simply caulk it in place over the weep hole. **PopMech**

TOOLS & TECH

MAKITA IMPACT GOLD DRIVER BITS
(FROM $4 FOR A PACK OF FOUR BITS)

Impact drivers are seeing increased use because of the speed with which they drive screws and lag screws, often without a pilot hole. However, these tools also generate upward of 300 inch-pounds of torque, which can easily destroy a bit, fastener, or workpiece. Makita's Impact Gold screwdriver bits are designed to deal with the harsh forces of impact drivers. The product line-up also includes socket sets and nut setters.



WHY WE LIKE IT

The unusual shape of these bits allows for a slight amount of torque-absorbing twist that reduces stress on the tips, so they're less likely to break. Manufactured from a wear-resistant steel alloy, they also fit tightly within the screw for fewer stripped heads. Best of all, they're reasonably priced.

? GOT A HOME-MAINTENANCE OR REPAIR PROBLEM? **ASK ROY AND DAVID.**

Send your questions to **pmhomeclinic@hearst.com** or over Twitter at @PopMechHome or to Home Clinic, Popular Mechanics, 300 W. 57th St., New York, NY 10019-5899. While we can't answer questions individually, problems of general interest will be discussed in the column.

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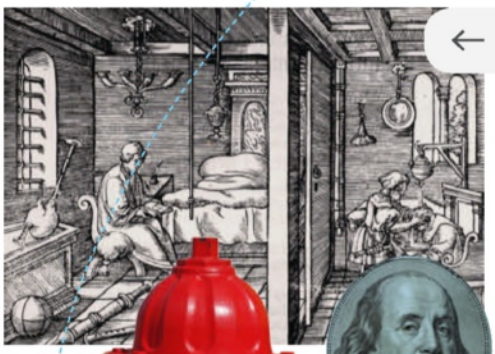
Firefighting

From primitive pumps to high-tech drones, we blaze through the past and peek into the future of flame dousing. BY AMANDA GREEN





← **Dalmatians become firefighters' best friends in the late 19th century, when they are used to protect fire-carriage horses.**



THIRD CENTURY B.C.: Ctesibius of Alexandria, a Greek inventor, designs the first hand-operated fire-extinguisher pump. Similar pumps surface in 16th-century Europe.

1648: New Amsterdam governor Peter Stuyvesant appoints fire wardens to patrol and enforce fire codes. In 1658 men begin using wood rattles to alert citizens to a fire.

1672: Dutch painter Jan van der Heyden develops the first fire hose, made of leather with copper fittings.

1721: British inventor Richard Newsham patents the first fire-engine pump, a twin-cylinder single-acting pump on a wheeled cart. A bucket brigade fills the cistern while a few men work the cross handles to shoot water as far as 135 feet.

1736: Benjamin Franklin organizes Philadelphia's volunteer brigade, the Union Fire Company.



1801: Frederick Graff, chief engineer of the Philadelphia Water Works, patents a post-style fire hydrant resembling what we use today.



1813: British captain George Manby invents the Extincteur, a 3-gallon copper cylinder that uses compressed air to spray pearl-ash solution from a tube. Fired up, he later creates a device for catching people who jump from burning buildings.

1853: Miles Greenwood and two fellow Cincinnatians invent the first practical steam fire engine. The city soon organizes the first professional fire department in the U.S.

1905: PopMech reports that "motor fire engines are rapidly replacing the old horse-drawn machines wherever practical in England." The trend soon carries over to North America.

1944: Only *you* can prevent forest fires, but Smokey Bear helps spread the message.

1974: In *The Towering Inferno* the world's tallest building becomes the world's biggest torch. The film is based on two books, both inspired by the World Trade Center.



2009: Segway Robotics' RPM firefighting robot can carry 400 pounds of equipment at 18 mph and shoot 10 gallons of water per second. But it can't rescue kittens from trees.

2014: Coming soon to a sky near you: drones that use infrared cameras to map out wildfires without endangering human heroes.

PHOTOGRAPHS BY GETTY IMAGES (DOGS, CTESIBIUS, FRANKLIN, HYDRANT), SEGWAY INC. (SEGWAY), ALAMY (SMOKEY BEAR, FIREMAN)



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